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The Cover: Lightning, one of the chief hazards to electric power lines, does not always cause outages, especially on modern lines. No outage resulted from these two strokes which occurred a few seconds apart near the Bonneville-Grand Coulee 230-kv line in the State of Washington. For further details see pages 541–2.

Photo courtesy Bonneville Power Administration

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HIGH LIGHTS . . .

Electrochemical Installations. Electrical characteristics of various electrolytic cells for aluminum, magnesium, chlorine, copper, and zinc, and the requirements that such characteristics impose on the electric equipment are discussed from the viewpoint of the electrical engineer. A typical installation of conversion equipment for an electrolytic process plant is given, and the reasons for selecting the particular types of electric equipment and its physical and electrical arrangement are presented (*Transactions pages 733–41*).

Gas-Filled Cable. Improvement in gas-filled cable since 1938, covering the whole range of voltage ratings from 10 kv to 138 kv, is discussed. The divisions considered are: low-pressure gas-filled cable systems, 10 to 40 kv, operating at gas pressures from 10 to 15 pounds per square inch; medium-pressure systems, 40 to 69 kv, operating at gas pressures from 24 to 40 pounds per square inch; and high-pressure systems, 69 to 138 kv, operating at gas pressures from 150 to 200 pounds per square inch (*Transactions pages 719–26*).

Cellulose Insulation. Factors of major importance affecting the rate of mechanical deterioration of cellulose insulation are temperature applied and the presence of oxygen and moisture. In general, the mechanical life of the insulation is reduced by one half for each doubling in water content. Deterioration promoted by oxidation is most effective at temperatures below 120 degrees centigrade and is accelerated by the presence of moisture (*Transactions pages 742–9*).

Short-Circuit Analysis. An analysis is made of power-leg-to-ground and light-leg-to-ground short circuits, with formulas for line-to-line and three-phase faults, and of short circuits on the secondary circuits of single-phase transformers supplied from three-phase systems. The effects of resistance in limiting short-circuit currents and the voltage rise of the secondary neutral above ground potential caused by transformer failure and resistance to ground also are considered (*Transactions pages 757–64*).

Motor Insulation. In accelerated temperature and moisture tests on sample motors, insulation resistances and dissipation factors appear to have more consistency and significance than they have been given credit for. Based on limited data, motor insulation appears to be more vulnerable to adverse moisture conditions than to moderately excessive temperatures (*Transactions pages 707–12*).

Static Electricity as an Incendiary. The origin of a number of "mysterious" fires and explosions occurring in connection with gasoline and other inflammable materials has been traced to the unsuspected presence of static electricity, by investigators who knew what to look for. Case histories of two such gasoline fires have been presented in detail (*pages 501–08*).

The Electromagnetic Field. In a review of the development of electromagnetic theory, the widely taught concept of moving lines of force in a magnetic field, when applied to open circuits, is criticized by a well-known physicist as "wrong in theory and disproved by experiment" (*pages 511–16*).

Bimetal-Type Wattmeter. Experiments with a bimetal-type thermal wattmeter indicate that high torque is obtainable with this meter by taking advantage of the "internally heated" principle which offers maximum heat-transfer efficiency and gives a time-of-response characteristic much closer to the ideal simple exponential than has been attained in commercial meters in the past (*Transactions pages 764–70*).

Amplidyne Generator. The steady-state theory of the amplidyne generator is substantiated by comparison of experimental data obtained on a test machine with results calculated from the machine constants. Effects of brush losses, commutation, and over- and undercompensation on the operation of the generator are explained (*Transactions pages 750–6*).

Locomotive Control. Application of a resistor transition scheme to a modern a-c locomotive produced improvement in the acceleration of the locomotive, reduction in arcing duty on the tap switches as shown by almost complete lack of any arc noise, and much smoother operation of the locomotive when notching (*Transactions pages 727–32*).

Need for International Understanding. An engineer of wide foreign experience cites the simple and controllable circumstances that lead often to international misunderstandings. He points out that stable international relationships can grow only out of the intelligence and conscious effort of the individual (*pages 525–6*).

Vocational Education. Some of the factors affecting future trends in vocational education in the United States are analyzed by the Connecticut state commissioner of education, who emphasizes the need of new attitudes if the overacademic tendency of our schools is to be balanced by worthwhile vocational training (*pages 520–3*).

Conservation Through Good Engineering. A wartime policy aimed at the conservation of materials by educating users of electric apparatus to apply equipment more closely and lay out systems with the least possible use of strategic materials has been established by the AIEE technical program committee (*page 524*).

National Salvage Campaign. A salvage program in every plant is the theme of the WPB campaign to collect throughout the United States idle materials which are available for scrap and which can be put into the production of vital war goods (*page 535*).

Rural Electrification. The steady progress in the application of electricity to agriculture indicates that a new branch of engineering—electroagricultural engineering—and a new industry to supply necessary equipment are emerging gradually (*pages 517–20*).

Calculation of Fault Currents. A simplified procedure for calculating short-circuit currents, which has had a year's trial use with satisfactory results, is now recommended by an AIEE committee for general use (*pages 509–11*).

Ignitron rectifiers. More than 2,000,000 kw of ignitron rectifier units have been purchased by the electrochemical industry. Primary installations for these large power concentrations are described (*Transactions pages 713–18*).

Pacific Coast Meeting. For those unable to attend the 27th AIEE Pacific Coast convention, September 9–11, an eyewitness account appears in this issue (*pages 524–5*).

Coming Soon. Among special articles and technical papers currently in preparation for early publication in *Electrical Engineering* are: an article describing an electronic circuit for determining power-angle oscillations of synchronous motors during the period of hunting by M. J. DeLerno (Enrolled Student) and R. T. Bassett (A'42); an article on carrier-current relaying and communication on the TVA system by M. S. Merritt (A'38) and T. D. Talmage (M'40); an article relating to national efficiency during wartime by G. A. Gaherty; a report of the AIEE Engineering Foundation research project pertaining to the stability of impregnated-paper insulation; two papers on circuit-breaker performance, one on the problem of switching large capacitor banks by T. W. Schroeder (A'37), E. W. Boehne (M'37), and J. W. Butler (M'38) and the other discussing the response of high-voltage circuit breakers to transient recovery voltages of very high frequency, by R. C. Van Sickle (M'37); a paper on the relative expense for service restoration with different types of overcurrent protection for distribution circuits, by G. F. Lincks (A'37) and C. R. Craig, and a paper by Charles E. De Leuw, describing the first unit of the $64,000,000 Chicago Subway, which is expected to be completed and in operation early in 1943.

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Detecting the Saboteur

Static Electricity

Gasoline Fires

ROBIN BEACH
FELLOW AIEE

Dreadnaughts of the highway pictured above were victims of a fire caused by a tiny electrostatic spark. The trailer gasoline-tank truck (right) exploded and the huge motor carrier (left) was completely destroyed. The violation of safety practices in the handling of gasoline and other inflammable products also leads frequently to economic waste and loss of life. This article outlines the procedure followed in two cases for detecting the origin of electrostatic sparks and for correcting the hazardous conditions that caused them.

STATIC ELECTRICity, as encountered in industry, may well be likened to a subtle foe, the saboteur, whose sinister purpose is not suspected until too late, after the harmful blow is struck. When the facts become known, it is an amazing revelation to learn how extensively the tenacles of this destructive agent, static electricity, reach out in their depredations upon industrial production. In some industries static electricity is ever active in starting fires or causing explosions, as for example in the manufacture of cereals, the proofing of fabrics, the making of explosives, and the handling of petroleum distillates and other highly inflammable products. In other phases of industry, it leads to the curtailment of production, as in the clogging of printing presses and the destruction of paper during manufacturing processes. The textile industry feels its presence through the development of imperfections of products, wherein the repulsion of electrified fibers of thread blurs the definition of patterns. In the photographic industry, static electricity causes the halation, marking, or puncturing of films. These are but a few of the many industries that are harassed by its destructive attacks.

In the petroleum industry, among others, fires and explosions have occurred, wherein the probable causes have not been determined, although thorough investigations perhaps would have revealed these catastrophes as being of static electrical origin. In all these industries where highly inflammable or explosive products are manufactured, transported, or used, fires and explosions occur

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During the technical investigations and the laboratory tests in connection with this article and while it was in the process of preparation, many individuals generously assisted the author. He wishes to acknowledge in particular the co-operation of the following: Edward F. McCrossin, McCrossin and Company, Engineers, New York, N. Y.; N. D. C. Pitcher, vice-president, American Casualty Company, Philadelphia, Pa.; Edwin W. Higgins, attorney, Norwich, Conn.; Lucius F. Robinson, Jr., attorney, Hartford, Conn.; and W. J. O'Donnell, Preferred Accident Insurance Company of New York, N. Y.

from time to time for which no known causes are attributed. Writing "unsolved" as the finis to these unfortunate episodes merely gives recorded expression to the inability of the investigator, first, to recognize among the various elements of evidence a trend toward a probable hypothesis of the source of ignition, and second, to reconstruct from a mass of gathered information a rational pattern of primary facts and complementary data that should strongly support a deduced "competent producing cause" of the fire or explosion.

THE INVESTIGATOR: TRAINING AND EXPERIENCE

Experience in exploring the scenes of disaster, ability to make accurate and critical examinations of debris as well as to formulate logical conclusions from such findings, and facility in gathering a full complement of facts both from personal observations and from interested individuals—all are characteristic attributes which distinguish the successful investigator. In addition he must possess an extensive background of scientific knowledge, natural explorative capabilities, and an adeptness in applying simple experimental confirmations of propounded hypotheses, in order to serve effectively in establishing "causes" from observed "effects." In order to be able to trace every hidden line of suspicion involving static electricity as a likely cause of the ignition where fires or explosions have occurred to inflammable products, and to gather and identify all such indicative clues and evidence as found at the scene, he should certainly have specific knowledge of the generation and behavior of static electricity.

These detectivelike services offer to the investigator with imagination and resourcefulness attractive opportunities for interesting, explorative, and critical study. Such investigations savor somewhat of the technique of crime detection, with static electricity characterized as the suspected saboteur. What evidence is obtained consists, by nature, mostly of the circumstantial type. The laboratory and the scientific approach are indispensable in developing a chain of incontrovertible evidence against this wily saboteur.

As information—either facts from observation or experimental data—becomes available during the investigation of a fire or explosion, an excellent procedure in attempting to determine the most probable cause of ignition is first to list every conceivable possibility that has any support in fact for the case under consideration. Then, with all known facts at hand, the investigator should devote a critical study to each of the proposed possibilities, eliminating those which possess little or no supporting proof. Through further speculation, study, and synthesis of facts and data, sometimes a supporting, although at first perhaps a nebulous, pattern of related findings leads to the substantiation of one, or even two, of the suggested causes.

In some instances, inexperienced consideration of the assembled facts has led to misconceptions or to erroneous interpretations from which no tenable theory for the origin of the fire could be derived. In such dubious and perplexing cases, the facilities of the experienced and qualified investigator become of inestimable value. Quite probably, in his study of other disasters, he has discovered that some fires and explosions, the causes of which likewise were at first shrouded in uncertainties, seemingly occurred under similar, marked, and perhaps attention-arresting, patterns of unusual circumstances or of striking peculiarities. Experience with such exceptional cases provides the investigator with a wealth of knowledge concerning the vagaries of fire origins, which aids him immeasurably on critical occasions in marshalling the many vague and weak clues to his problem into a strong and irrefutable chain of evidence to support his claim of the most probable cause of the fire.

Two interesting examples of fires traced to static electric origins are cited herein and explained, to illustrate the investigator's problems, his explorations for the facts, and his recourse to science for supporting evidence, in attempting to ascertain the probable causes for the ignition of inflammable gasoline vapor–air mixtures wherefrom the burning resulted in extensive secondary damages. Both examples relate to fires that were started during the refilling of underground gasoline-storage tanks at garages. The first case of fire occurred at a privately owned filling station on an estate, and the second relates to a fire at a commercial filling station on a large garage property.

THE FIRST CASE

An underground 550-gallon gasoline-storage tank, which was located at the side of and near the entrance to a garage on an estate, was being filled from a tank truck of conventional type. The hand-operated pump for the storage tank was located at the end of the tank nearest the garage door. About eight feet away at the remote end of the tank, a $1^1/_2$-inch vent pipe, which extended above the ground to a height of about four feet, was capped with a weather-protective hood. Between these, at about the middle of the tank, a conventional $2^1/_4$-inch fill pipe was connected into the underground tank at its lower end and terminated at its upper end in the fill receptacle with its screw cap and cover plate, which extended a little above the level of the ground.

About a minute and a half after the flow of gasoline from the truck into the storage tank started, fire was observed to burst out of the vent pipe and the fill hole of the storage tank. The driver, who at the time was at the cab end of the truck, immediately shut off the valve at the rear end of the truck, started the engine, and quickly drove out of range of the fire. Subsequently the garage and the adjoining buildings caught on fire, and considerable damage resulted.

Many months later, the author was called upon to investigate the case for the purpose of trying to determine the initiating cause of the fire. He then learned that

other investigators who had worked on the problem had given it up as an "inexplicable mystery." In trying to obtain all the available and pertinent information, he first questioned many people who had various interests in the matter, including the personnel employed on the estate and by the oil company. Then, too, he conducted an examination of the gasoline tank which he partly excavated, and also made certain electrical tests at the premises. Later, valuable data were obtained from various supplementary experiments and tests.

From all these sources, applicable information was gradually disclosed which led to the formulation of a probable solution to the problem of how the fire started. The essential facts and data are summarized briefly in the following paragraphs:

1. The local weather record for several days prior to and at the date of the fire showed an extremely dry, hot period.

2. It was stated that, at the time of the disaster, during the forenoon, no fires of any kind, such as burning gas jets, stove fires, lighted lanterns or candles, or bonfires, had existed within several hundred feet of the storage tank and garage.

3. Also the investigators were told that no electric apparatus, such as electrically driven pumps, compressors, and other commonly used domestic equipment, including electric lights or heaters, were either in operation or being started anywhere near the filling station at the time just prior to the outbreak of the fire.

4. One of the workmen at the estate declared that he was in full view of and near the filling station at the moment the fire was observed, and he corroborated the truck driver's statements that at the time the driver was at the cab of the truck preparing the sales ticket, that he was not smoking or lighting a match, that the engine of the truck was not running, and that no pumps or other gadgets were being operated from the storage battery on the truck.

5. The truck driver was reported by the oil company to be a careful operator, to have an excellent service record, and to enjoy a reputation for honesty and reliability.

6. The truck driver further stated that, in conformity with his company's regulations and practices, after he had backed the truck to within about ten feet of the underground tank, he first connected the ground wire from the truck to a grounding clip on the vent pipe of the storage tank, and then placed the hose nozzle in the fill pipe of the tank, afterwards connecting the hose to the outlet valve at the rear of the tank truck. When all was in readiness, he opened the valve which permitted the flow of gasoline. He then went forward to the cab to prepare the sales slip for the delivery of gasoline.

7. The gasoline flowed through the hose by gravity from the truck into the storage tank. The standard fill hose on this truck permitted a rate of flow of about 50 gallons per minute, and the meter later indicated that a total of about 75 gallons of gasoline had been discharged by the time the fire started. This finding was supported by subsequent tests in confirming the fact that about a minute and a half was actually the time required for the discharge of the registered amount of gasoline.

8. After the fire, investigators found a part of the ground wire still connected to the vent pipe, where it had evidently been broken as the truck was hastily driven away—a fact which supported the driver's statement that he made the connection in conformity with the company's code of safety regulations.

9. The driveway where the truck stood was composed of a foundation of crushed rock with a surfacing of blue stone. Its electric resistance was measured between a thoroughly prepared ground and a metal plate which was fitted into good contact with the roadway surface—the plate representing the combined area of roadway contact by the truck tires. This resistance was found to be of a very high order—measuring "infinity" on the 100-megohm megger, this being the only one available at the time of the tests. Later tests on similar roadbeds indicated that this resistance was probably of the order of 10^{11} or 10^{12} ohms.

10. The shoes which the driver had worn at the time of the fire were also measured to determine their resistance from the bare feet through the leather soles to an artificial ground consisting of a thick layer of pulp newspaper, thoroughly soaked in brine. The resistance from the body to this artificial ground, through both shoes in parallel, was found by the megger to be about 5 megohms, or approximately 10 megohms per shoe.

11. The 550-gallon storage tank had been purchased, second-hand, from a jobber, who had painted the tank, the vent pipe, the fill pipe, and the fittings with several coats of heavy black paint. A sample of the paint, taken from the tank and chemically analyzed, was found to be composed of a base of titanium oxide and a binder of asphalt—both of which substances possess excellent insulating and dielectric properties. In consequence of this, the metal of the tank was well insulated from the surrounding ground. Of course it should have been thoroughly grounded, but unfortunately little if any thought is in general given to the matter at the time of installing tanks. As installed in this case, the metal of the tank therefore constituted one plate of a capacitor, with the ground as the other plate, and the intervening paint served as the dielectric.

12. During the excavation for the original installation of the tank, large rocks had been encountered. Consequently, the tank, instead of being buried to the recommended depth of at least 24 inches from its top surface, in order to insure the presence of moist earth around it for intended grounding purposes, actually was covered by less than 6 inches of soil. An exploratory excavation revealed, in addition, that the entire bottom of the tank and parts of its sloping sides were practically free from contact with the earth and that it was essentially resting upon the large rocks as a foundation. At the time of inspection an attempt to measure the capacitance of the metal of the tank to ground was not successful, as the subsoil was thoroughly wet from a long rainy spell; also parts of the tank had been disturbed since the fire, and the dielectric resistance at this time was only a few ohms. However, from the dimensions of the tank, and by taking into consideration the cavitation conditions of the soil, a very rough calculation showed its capacitance to be of the order of 500 micromicrofarads, that is, 500×10^{-12} farad.

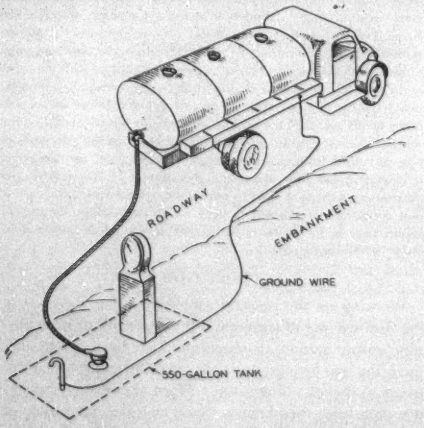
A SOLUTION

Working on the rational assumption that the start of the fire was not of common origin, as each of such possible sources seemed reasonably to have been eliminated, attention was focused upon the possibilities of static electricity as the offending cause. Since almost no quantitative data were then known concerning the magnitude of potentials and charges developed on the bodies of rubber-tired vehicles as they ran along the highways, or concerning the conditions under which these static electric charges were retained on vehicles when they stopped, a special research study was devoted to the problem. The results of this investigation were reported by the author in the May 1941 issue of *Electrical Engineering*, under the title "Static Electricity on Rubber-Tired Vehicles."

Tank trucks, like the one here concerned, were commonly found to generate, between their bodies and ground, 15,000 to 25,000 or more volts, while running

along dry highways. Under favorable conditions these voltages sometimes persisted for hours after the vehicles came to rest. When the tires and the roadway were dry the electric charges on the vehicles were impounded there by the excellent insulating properties of the rubber tires and the roadway materials. Also measurements of the electric capacitance of the metallic structures of tank trucks to ground were taken, and the capacitance values found to be of the order of 700 to 1,200 micromicrofarads.

Let it be assumed that the tank truck under consideration retained a charge at several thousand volts and that it was electrically connected to the underground storage tank both by the ground wire and by the fabric-enmeshed wires contained within the fill hose. Since the storage tank and its vent and fill pipes were all insulated from ground by the layers of paint, electric charges flowed from the truck body to the metal of the underground tank, as a capacitor, at a rate determined by the resistance in this completed electric circuit. The electrical conditions existing here are represented schematically by the conventional equivalent circuit diagram of Figure 1. As shown in this figure, the electric resistance from the tire treads through the roadway material to the earth surrounding the tank was of the order of possibly



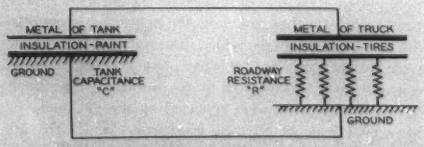


Figure 1. The approximate equivalent electric circuit represents the condition shown above, wherein the insulated underground gasoline storage tank is being charged from the electrified tank truck

100,000 megohms. Therefore, the electric charge from the tank truck would be conveyed to the storage tank in a slow logarithmic growth according to the equation

$$q = Q_F - Q_F \epsilon^{-\frac{t}{RC}}$$

where q represents the charge on the tank at any time t; Q_F symbolizes the maximum charge that the tank can acquire for a given value of voltage; R represents in ohms the resistance of the electric circuit between the truck, as a charged capacitor, and the storage tank as a charge-receiving capacitor—an enormous value of resistance which is numerically about equal to that through the roadway from the tire-treads to electric ground; C indicates the value in farads of the capacitance of the storage tank; and ϵ stands for the base of the Napierian system of logarithms, the approximate value of which is 2.718.

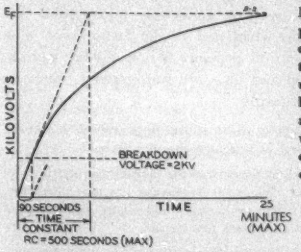


Figure 2. Approximate growth of voltage across the insulated underground gasoline storage tank, as a capacitor, while it is being charged from the electrified tank truck

The growth of voltage across the capacitance, as formed by the insulated storage tank and ground, also increases in a like manner to the charge. This is true because the voltage increases in exact proportion with the increasing charge in the capacitor, as shown by the basic relationship: volts = coulombs/farads. The graph of this growth of voltage is shown in Figure 2.

During the time that the voltage was building up on the storage tank, gasoline was being discharged from the truck into the tank. A volume of vapor equal to the volume of in-flowing gasoline was being simultaneously expelled through the vent pipe. The expelled vapor, being nearly four times heavier than air, flowed directly down to ground, covering the area above the tank and adjacent to it. Some of this vapor mixture with air naturally seeped into the ground around the tank through the interstices of the soil. Had the vent pipe been properly installed to a height of ten feet above the roof of the adjacent garage, the probability of the gasoline vapor–air mixture maintaining its inflammability through the intervening distance to the tank would have been practically nil.

Additional measurements showed that the paint on the tank was in a somewhat deteriorated condition, and that it would probably be punctured under the stress of

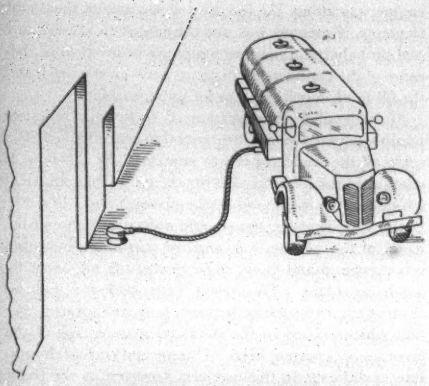


Figure 3. From the diagram, several violations of recommended safety codes may be observed

1. *The fill pipe should be located not less than five feet from the garage structure*
2. *The engine of the truck, which should not have been running, is within six feet of the combined fill and vent pipe*
3. *A separate vent pipe, equal in cross section to the fill pipe, should extend ten feet above the highest point of the adjacent garage*

approximately 2,000 volts. When this took place, a spark would be permitted to pass through the paint and to discharge the storage tank. Upon the occurrence of such a spark in this case, the gasoline vapor–air mixture, if within the range of inflammability, would ignite, and the flame propagation would instantly travel back to the sources of the vapor issuing from the tank—one being the near-by vent pipe and the other the fill pipe.

Furthermore, as soon as one spark occurred and the storage tank was electrically discharged, the cycle of recharging it and of restoring the voltage across the tank until another discharge spark took place could continue until the truck body had finally dissipated its entire electrification.

THE SECOND CASE

In the second illustrative case a series of circumstances occurred that was remarkably similar in some respects to those cited in the first example. Here an underground gasoline tank at a large filling station was rated at the same storage capacity as the other, 550 gallons, but this tank was not provided with the customary type of vent pipe. The approved type of vent for this size of storage tank as specified by the National Board of Fire Underwriters, is a $1^1/_4$-inch pipe "extended to a location where the vapors discharging from the vent will be readily diffused without danger of ignition." The regulations for the City of New York require a vent pipe of the same diameter as the fill pipe, and if a building is within 30 feet of the tank, the vent pipe must extend up the side of the building to a height of 10 feet above the roof. Instead of having a vent of an approved type, this tank was equipped with a very old, unusual, and dangerous combination of fill pipe and vent pipe formed into a single unit. The arrangement of the parts of this combined unit, including the inserted hose nozzle, is shown in the cross-sectional sketch of Figure 4.

From this sketch, it can be observed that a substantial outer galvanized-steel pipe was connected at its lower end into the storage tank, while its upper end supported the fill head, which protruded about 6 inches above the ground level. The fill pipe was contained coaxially within this outer casing, the upper end consisting of a $2^1/_2$-inch length of 2-inch brass tube which was secured to and supported from the fill head. The remainder of the fill pipe was 20 gauge zinc of $2^7/_{32}$-inch inside diameter that was sweated over the upper 2-inch brass section. The lower end of the fill pipe extended about 12 inches down into the storage tank. The space between the inner and outer pipes, which consisted of only $^1/_{32}$-inch radial clearance, was intended to serve as the vent for the tank. However, this permitted only a very small vent area of 0.22 square inch, whereas the fill pipe had a cross-sectional area of 3.15 square inches. Six $^1/_4$-inch holes, which extended through the steel plate in the top of the fill head, connected with the enlarged vent space between the brass fill pipe and the coupling at the top of the outer support pipe. While the tank was being filled, the displaced gasoline vapor was expelled, in part, through the vent space provided for this purpose between the inner and outer pipes and through the small holes into the atmosphere above the fill pipe, but because of the gross inadequacy of this venting area, much of the vapor was forced out through the fill pipe.

During the operation of filling the tank, the nozzle of the fill hose, which had an outside diameter of $1^3/_4$ inches, was inserted into the 2-inch fill pipe, extending down into it about 12 inches. Ordinarily, when the tank was not being refilled, a brass vent cover, hinged to the fill head, was shut so as to cover both the fill pipe and the vent holes. This cover could be locked in its closed position by a padlock as a protection against the theft of gasoline.

When a loose hose nozzle discharges gasoline into a properly vented storage tank, it acts on the principle of an inspirator in causing air to be drawn down into the tank. There the mixture of the air with the gasoline vapor may produce a dangerous condition of inflammability, leading to possible fires or explosions. Even the so-called vent pipe may introduce a similar situation of dangerous vapor–air mixture within a tank. In general, a vent pipe would be more appropriately called a "breather," because air flows inward through it when gasoline is being pumped out and the vapor–air mixture flows outward when gasoline is being discharged into the tank. In the peculiar and dangerous type of combined vent- and fill-pipe construction employed in

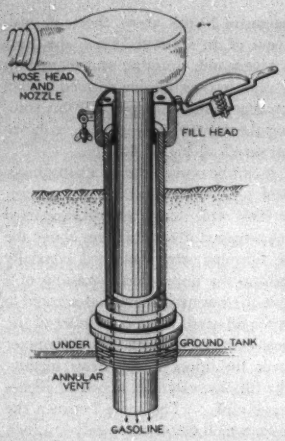


Figure 4. Diagram of the combined fill and vent pipe, showing (1) the gross inadequacy of the annular vent—only 1/15 of the cross section of the fill pipe; (2) the hazardous design which combines vent pipe and fill pipe in one unit; (3) the position of the hose nozzle in the fill pipe and the locations where igniting sparks may occur

this case, the vapor–air mixture was discharged at a high velocity, not only through the six small orifices but also through the fill pipe, during the time that the tank was being refilled with gasoline. This geyserlike condition of combustible gas, and the presence of the inflammable mixture at and near the orifices of the tank, both constituted particularly serious sources of potential fire hazards.

At the time that the fire occurred, the storage tank was in the process of being filled from a tank truck drawn up alongside, as shown in Figure 3. The fill hose used in this instance also was rated at approximately 50 gallons per minute, and about 80 gallons of gasoline had already been discharged, when the fire suddenly burst out of the combined fill pipe and vent pipe.

The engine of this tank truck, unlike that in the first case, was running at idling speed during this period—a circumstance flagrantly in violation of various codes of safety recommendations. The close proximity of the truck's engine to the fill pipe suggested the possibility of ignition of the expelled gasoline vapor–air mixture: (1) by electric sparks from a punctured high-voltage sparkplug cable, (2) by electric sparks from a defective distributor head in the ignition system, (3) by exhaust flames issuing from a loose or broken gasket in the exhaust pipe, especially at the manifold of the engine, and (4) by glowing carbon particles being blown out of the exhaust pipe.

Each of these four possible sources of ignition was given critical consideration. It was clearly recognized that if the engine of the truck had been operating under heavy load any one of these offending elements, if present at all, might have occurred at its severest intensity, and in consequence could have constituted a hazardous source of ignition in the presence of a combustible mixture of gasoline vapor and air. On the other hand, while the engine was idling, the intensity of any one of these four elements, if present, was not considered to present any real probability of igniting a mixture believed to be, because of the considerable distance between the truck and the fill head, much too lean for inflammability.

After detailed consideration of those four remotely possible causes for the fire, attention was directed to a study of the static electricity generated by the flow of gasoline in the fill hose, as being the most likely source of ignition of the inflammable gas mixture. As a first step in this investigation, the electric resistance between the metal of the storage tank and the surrounding ground was measured and found to be practically nil—actually about six ohms. This result gave evidence that no electrostatic capacitance between tank and ground, like that which existed in the insulated storage tank of the first case, was present here. Unique and critical circumstances did exist in this instance, however, as the result of the unsafe and careless methods employed by the operator of the gasoline truck in refueling the tank, and of the hazardous nature of the combined vent and fill pipes.

In the process of refilling the gasoline storage tank, the operator inserted the hose nozzle loosely into the fill pipe and then opened the valve at the side of the tank truck. He had neither made any previous ground-wire connections from the tank truck to an adequate and satisfactory ground, nor lowered a drag chain to ground the chassis of the truck to the dirt surface of the yard. Had either of these customary safety practices been employed, the fire most probably would have been averted. Also, fire undoubtedly would have been prevented by simply using, in the first place, the highly approved and extensively used "screw-in" type of hose nozzle, rather than the hazardous "loose" type. By municipal regulations, the screw-in hose nozzle is required in the filling of gasoline storage tanks in practically every large city in the United States. This attachment consists of a separate short piece of pipe, 2-inch pipe in this case, which is threaded at each end to enable it to be screwed securely into the fill pipe at one end and into the brass head of the hose at the other end.

The standard fill hoses in use for refilling storage tanks, as previously stated, contain wires interwoven in the hose fabric to connect the metal of the truck to the hose nozzle, so that during unloading operations, it will presumably ground the truck body to the storage tank. If the nozzle of the hose had made proper and continuous metallic connection with the fill pipe in this instance, the truck body would have been electrically grounded. Unfortunately, however, the loose hose nozzle cannot be relied upon as a means of grounding a tank truck, for the reasons to be described.

Dielectric tests taken on samples of gasoline by means of a standard American Society for Testing Materials test cell disclosed that its dielectric strength was of the same general order as that for high-grade transformer oil.

Most of the 100 or more tests made by the author showed dielectric values higher by several per cent for gasoline than for the oil. This finding has a particularly significant bearing upon the unreliability of the loose hose nozzle as a means of grounding the body of the truck. When the hose nozzle was placed in the fill pipe, it made contact with it at two locations, one being at the top of the fill pipe and the other at the lower end of the nozzle. Obviously at this lower end where the fluid discharges, the pipe was kept wet with the splashing gasoline—a condition which established and maintained an excellent insulating film between the metal of the nozzle and the pipe. Since the fill pipe also served in this instance to vent the tank, a gasoline insulating film was undoubtedly produced from the rising spray at the top between the nozzle and the head of the fill pipe, and in addition this was augmented by an insulating barrier resulting from layers of nonconducting metallic oxides and possibly from intervening particles of dirt. The metal structure of the truck was, of course, well insulated from ground by the dry rubber tires. In consequence, whatever electric charges were generated on the metallic structure of the truck and the hose by the flow of gasoline to the storage tank were impounded there by virtue of the insulated hose nozzle until a voltage to ground was developed of sufficiently high intensity to cause the ultimate passage of a spark.

When gasoline was permitted to flow through the fill hose into the storage tank, it became charged with electricity by the principle of "contact difference of potential." Under such circumstances the liquid generally acquires a positive polarity, and the counterpart negative charges are thereby contained in and impounded on the related metal parts—in this instance the tank truck and its connecting hose, because they were insulated from ground. The author employed information, which he also substantiated by test, to the effect that gasoline, in flowing at the rate of about 50 gallons per minute, produces electric charges in the flowing gasoline which correspond to a current of about 3×10^{-8} ampere.

Since the hose in this case was rated at a flow of approximately 50 gallons per minute, the rate at which the positive electric charges were conveyed into the storage tank and the negative charges stored in the insulated metallic system of the truck and hose was 3×10^{-8} ampere. For the period of approximately 100 seconds during which the 80 gallons of gasoline flowed into the storage tank just prior to the fire, a total electric charge of 3×10^{-6} coulomb accumulated on the truck. With respect to ground, this truck possessed a capacitance of approximately 750 micromicrofarads, or 7.5×10^{-10} farad. From the basic equation that volts = coulombs ÷ farads, the voltage which existed from the truck and its hose to ground was readily calculated and found to be approximately 4,000 volts.

Apparently when this value of voltage was attained after the passage of the 80 gallons of gasoline, one of the insulating films between the hose nozzle and the fill pipe disrupted under the increasing potential stress and thereby permitted the complete and instantaneous electric discharge of the truck, as a capacitor, through its ensuing spark. In the presence of the mixture of gasoline vapor and air at the proper proportion for inflammability, such a spark would be a "competent producing cause" for starting the fire.

The intensity of static electric sparks in relation to their ability to ignite an inflammable gas mixture is interesting to consider. During winter months a person scuffing over a woolen rug may readily store upon his body, as a capacitor, an electrification to a potential difference of 4,000 volts, or even more. By experiment, this voltage and charge have been found sufficient to ignite illuminating gas from a jet by bringing the knuckle close to the burner when the gas is turned on. Under approximately the same value of voltage, the truck being considered here, which had a capacitance of about seven times that of the human body, would have stored upon it approximately seven times the above quantity of electricity and, therefore, upon discharge, it would have given a spark of about seven times the intensity of that just cited as being sufficient to light a gas jet.

For the production of gasoline fires from electrostatic sparks of such short periods as existed here which result from the discharge of a capacitor, that is, from the sparking of the truck body through the hose nozzle to ground, the amount of heat energy contained in the spark is the true criterion for ignition. The heat energy required to produce the temperature of 1,760 degrees Fahrenheit necessary for the instantaneous ignition of an inflammable mixture of gasoline vapor with air at atmospheric pressure, particularly at ultrashort intervals of microsecond or less, has not as yet been determined. The author has been making a quantitative investigation of this problem, however, and hopes to have information available in the near future. In this instance the author computed from the known data the value of the electric energy liberated when the spark occurred at the fill pipe to discharge the truck body. From the basic equation, energy $= {}^1/_2QE$, he found the energy to be approximately 6×10^{-3} watt-second, or 1.44×10^{-3} calorie. As previously mentioned, this is about seven times greater than that required to light the gas jet from the charge liberated at a person's knuckle. The value of the current at the first instant of the discharge is probably of the order of several amperes. At start, it is limited only by the resistance in the electric spark. Thereafter the current quickly decays in a logarithmic manner, according to the equation $i = I_0 e^{-\frac{t}{RC}}$, where i represents the current at any instant t, and I_0 is the initial value of the current, which is numerically equal in this instance to $4{,}000/R$. The value of R is not only unknown here, but also, so little is known concerning the resistance of arcs, it cannot even be approximated within reasonable limits

without specific investigation. The time constant, $T=CR$, is very small, perhaps of the order of 7.5×10^{-7} to 7.5×10^{-8} seconds.

The hazardous type of combined fill and vent pipe used in this tank, the author was informed, would have been promptly disapproved by the National Board of Fire Underwriters. The dispelled vapor was exhausted at high velocity both from the small holes in the fill head and from the fill pipe as well—a dangerous condition in itself. The high ambient temperature on the day of the fire—82 degrees Fahrenheit—greatly expedited the admixture of air and gasoline vapor to the point of inflammability. So, therefore, when a spark occurred near the orifice of the fill pipe at the instant prior to the start of the fire, all the conditions for the ignition of the gas mixture were apparently fulfilled, and a fire ensued which completely destroyed the garage and several cars, a lubritorium, a sales display room, supplies, and offices.

CONCLUSIONS

From a critical study of all the available facts and data in each of the two illustrative examples cited in this article, several interesting conclusions were adduced. In each of the two cases, strong and well-integrated circumstantial evidence indicated "with a reasonable degree of certainty" that the fires were caused by spark discharges of electrostatic origin.

In the first case, none of the ordinary sources of ignition for the fire could be discovered which had any supporting evidence at all. The very unusual situation of the tank being unwittingly insulated from the ground provided a rational basis for concluding, with a reasonable degree of certainty, that a spark from the discharge of the electrified tank through the dielectric to ground caused the ignition of the highly inflammable gasoline vapor–air mixture.

Had the ground wire, which was so meticulously connected to the insulated vent pipe of the tank with the belief that this had grounded the truck, actually been joined to a well-grounded conductor, the electric charge on the truck would have been harmlessly discharged and no fire from this cause could have resulted. Likewise, had the vent pipe been connected to, and run up the side of, the adjacent building wall to the recommended height of ten feet above the roof, the expelled vapor would then have been too thoroughly diffused to produce an inflammable mixture with air at the outer walls of the buried tank.

In the second example, singularly enough, the fire occurred as the result of another very uncommon situation of a still different kind, and of a violation of well-established safety recommendations. The storage tank itself was quite well grounded, but no attempt had been made to ground the tank truck by either a ground wire or a drag chain. It was probably believed—if, indeed, any thought was given to the subject at all—that the grounding of the truck had been accomplished through the "ground wires" interwoven in the fill hose. But, as already explained, the hose nozzle was effectively insulated from ground by the high dielectric property of the intervening films of gasoline and metallic oxides, and, therefore, the tank truck and its connected hose were unknowingly insulated from ground—a condition which, during the handling of gasoline, is at all times most dangerous. Under such circumstances a single spark from an electrostatic discharge at the hose nozzle in the presence of the inflammable gas mixture would suffice to cause a fire or an explosion.

Then, too, the vent from the storage tank discharged its gas mixture into the air at the most unfavorable location, where the hazards of fire were greatest. The most dangerous location in the filling operations of a tank, where a loose hose nozzle is employed, is at the fill pipe, because static electric sparks here are known to have caused many fires and serious explosions. If the screw-in type of hose connection to the fill pipe had been employed, as has been recommended for years by the National Board of Fire Underwriters and by other safety organizations, the electric charge on the truck would have flowed harmlessly to ground, a high voltage from the truck to ground could not have been developed, as explained, and, in consequence, no fire could have occurred.

Other possible sources of fire may have been present in the second case, because the idling engine of the truck was located within a few feet of the fill pipe. Yet automotive vehicles by the thousands are daily serviced with gasoline, apparently with impunity, while their engines are running. With a wide experience in investigating the origins of gasoline fires, one would place little credence in a claim that the fire in this instance started from this cause. The high vertical velocity of the escaping gas mixture at the tiny vent holes and the fill hole would cause the gasoline vapor to become excessively diffused with air by the time it gravitated into proximity with the engine.

Thus, from these two and the many other casualties from gasoline fires and explosions that have been investigated by the author, he has found repeatedly that the so-called "inexplicable mysteries" of their origins generally dissolve into the commonplace when exposed to the illuminating facts and data revealed from an investigation of every pertinent channel of engineering knowledge and science by persistent, painstaking, and understanding research and study.

Finally, where gasoline fires and explosions have occurred, their origins have generally sprung either from the neglect of safe and accepted practices in the handling of gasoline on the part of the employees of the local oil companies or of garage attendants, or from the existence of unusual circumstances which were generally the outgrowth of inexcusable ignorance of the lurking fire hazards peculiar to the oil industry or of lack of intelligent supervision and inspection of the installations of gasoline-storage facilities.

Simplified Calculation of Fault Currents

A simplified procedure for the calculation of short-circuit currents was presented in an earlier report.[1] This procedure, outlined in this article, has been given trial use for over a year and has been found to be generally satisfactory for the purpose intended. Accordingly, it is now recommended for general use by the industry as a simplified method of approximating the magnitude of fault currents.

THE precise determination of short-circuit currents involves a calculation so laborious as to be generally impractical. Thus, some approximation is required, and a degree of judgment must be applied in any method proposed. This method presented here is based upon the determination of an initial value of rms symmetrical current with which multiplying factors are used for application purposes. It is proposed that it be used, where applicable, in place of the methods which involve the use of decrement curves. It is believed that this procedure is sufficiently accurate to serve as a reliable basis for the application of interrupting devices and for a preliminary basis for relay settings.

The recommended multiplying factors take account of generator decrement and the asymmetrical value of current as influenced by the system d-c time constant, and they are adjusted to make allowance for the increase in generator excitation required to maintain normal terminal voltage under load conditions. They neglect, however, such influences as generator voltage regulators and phase-angle differences between generator rotors, which have but little effect within the usual operating time of modern circuit breakers.

A comparison of the current magnitudes determined by the recommended factors with those calculated by more complicated methods after various time intervals is given in Figure 1. The time intervals selected correspond to breaker speeds of 2, 3, 5, and 8 cycles. The fault current and reactances are based on the system kilovolt-amperes. Curves are given for both the total rms current and the a-c component only, the difference between the two being due to the d-c component. The larger the d-c time constant, the more closely is the total rms curve approached, and the smaller the d-c time constant, the more closely is the a-c component curve approached. The time constant of the d-c component for which these curves were made is 0.15 second or nine cycles, which is larger than the values usually encountered in any equipment except generators. The d-c time constant may be expressed generally as equal to $(1/2\pi f)(X/R)$ in seconds, or $(1/2\pi)(X/R)$ in cycles, where X is the 60-cycle reactance and R the d-c resistance to the point of fault.

This report, sponsored by the AIEE committee on protective devices (J. R. North, chairman 1940-42) was prepared by a working group consisting of W. F. Skeats, W. M. Hanna, J. B. MacNeill, H. A. Travers, C. F. Wagner, and C. A. Woodrow.

Reprints of this report are being made available; see page 526 of this issue.

In this method of determining fault currents, symbols are used with the following significance:

E = leg voltage
X_1 = direct-axis reactance, either transient or subtransient as specified, in ohms per leg
X_2 = negative-sequence reactance
X_0 = zero-sequence reactance
R_0 = zero-sequence resistance

The type of fault (number of phases involved, with or without ground) which will result in the maximum fault current varies with the relative values of the different circuit constants.

The three-phase short-circuit current is E/X_1. The line-to-line short-circuit current is $\sqrt{3}E/(X_1+X_2)$. Since X_2 is usually equal to or greater than X_1, this current seldom exceeds 86 per cent of the three-phase short-circuit current, and, consequently, for line-to-line faults the three-phase fault-current value is generally satisfactory.

The line-to-ground short-circuit current is $3E/(X_1+X_2+X_0)$. Since X_2 is usually approximately equal to X_1 (using the subtransient value for X_1), this expression is often shortened to $3E/(2X_1+X_0)$. In practical cases, regardless of the value X_2, this last expression is satisfactory for determining the current in a double line-to-ground fault.

PROCEDURE

The following gives a résumé of the procedure and the various multiplying factors to be used with currents calculated by the formulas just stated. Tables I and II show what reactance quantity should be used for representing the machines in the positive-sequence network.

Circuit Breakers, Protector Tubes, and Fuses. Determine "highest value of rms symmetrical current for any type of fault" by E/X_1 or $3E/(2X_1+X_0)$, whichever is greater, except that when R_0 is greater than $5X_1$, no consideration need be given to the latter term. Use multiplying factors as given in Table I for specific type of apparatus.

The application of protector tubes requires also the calculation of minimum fault current with minimum connected synchronous capacity and symmetrical current using E/X_1 or $3E/(2X_1+X_0)$, whichever gives the lower value. Special consideration is required where tower-footing resistance can appreciably reduce this line-to-ground fault current. For further details reference may be made to a paper, "Protector Tubes for Power Systems."[2]

Fuses are rated on total current, and, as the time durations involved are very short, their required inter-

rupting capacity should be based on the total rms current at one-half cycle. Two cases should be considered:

1. In the general case, the current multiplying factor is 1.6, using subtransient reactance for all machines, and including both synchronous- and induction-motor contributions.

2. For fuses rated 15,000 volts or below with interrupting ratings not exceeding 3,000 amperes (except when applied on a generator bus), the resistance introduced by line and transformer is so great that the rms current of a maximum displaced wave in the first half cycle will not exceed 1.2 times the calculated symmetrical current, using subtransient reactance. Application on this basis may be considered safe.

Mechanical and Momentary Ratings. For many purposes, it is necessary to know the maximum possible rms current which can flow in the circuit. This is the current, including both a-c and d-c components, as calculated at one-half cycle. Allowing for over excitation of generators on account of load, the rms value of current as calculated for zero time is about 1.8 times the value calculated by dividing leg voltage by subtransient reactance. As there will always be some decay even in the first half cycle, however, a multiplier of 1.6 gives a safe figure.

In some instances, as when transmission line or cable reactance is an important factor in the limitation of current, the factor 1.6 may be higher than necessary. In such applications at 5,000 volts and below, the ratio of reactance to resistance is sufficiently low so that the d-c component decreases very greatly during the first half cycle. Thus within this voltage range, and except where the bulk of the power is supplied by generators at the point of fault, a standard factor of 1.4 may be used instead of 1.6. A standard factor is particularly desirable, in consideration of the difficulties of obtaining actual resistance figures and the distribution of the d-c component among contributing short-circuit sources.

Table I. Circuit Breakers, Protector Tubes, and Fuses

	Multiplying Factor	Reactance Quantity for Use in X_1: Synchronous Generator	Synchronous Motor	Induction Machine
A. Circuit-Breaker Interrupting Capacity				
1. General case				
Eight-cycle or slower breakers ‡	1.0	Subtransient*	Transient	
Five-cycle breaker	1.1			
Three-cycle breaker	1.2			
Two-cycle breaker	1.4			
2. Short circuits fed predominantly by large machines at the point of fault may be increased up to 20 per cent				
3. Air circuit breakers rated 600 volts and less	1.25	Subtransient	Subtransient	Subtransient
B. Mechanical Stresses and Momentary Rating of Circuit Breakers				
1. General case	1.6	Subtransient	Subtransient	Subtransient
2. At 5,000 volts and below, unless current is fed predominantly by directly connected synchronous machines or through reactors	1.4			
C. Protector Tubes				
1. Maximum rating				
2. Minimum rating—use minimum system capacity and minimum of E/X_1 or $3E/(2X_1+X_0)$	1.0	Subtransient	Subtransient	Subtransient
D. Fuses				
1. General case	1.6	Subtransient	Subtransient	Subtransient
2. At 15,000 volts or below with interrupting ratings not exceeding 3,000 amperes	1.2			

‡ Modern breakers are likely to be more effective than their slower predecessors, and, therefore, the application procedure with the older breakers should be more conservative than with modern breakers. Consequently, the factors to be used with older and slower breakers should be the same as for modern eight-cycle breakers.

* This is based on the condition that any hydroelectric generators involved have amortisseur windings. For hydroelectric generators without amortisseur windings, the subtransient reactance should be assumed equal to 75 per cent of the transient reactance for this calculation.

Table II. Preliminary Settings for Relays

	Multiplying Factor	Reactance Quantity for Use in X_1: Synchronous Generator	Synchronous Motor	Induction Machine
1. High-speed current actuated	1.0	Subtransient	Subtransient	Subtransient
2. Time overcurrent	1.0	Transient	Transient	

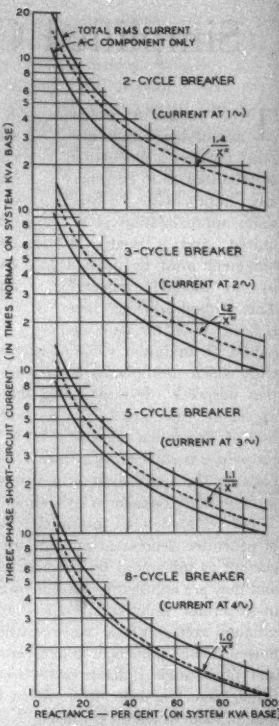


Figure 1. Comparison between decrement curve calculations and calculations by the proposed method

Low-Voltage Systems. Low-voltage air circuit breakers (rated 600 volts or less) are often instantaneous in operation and part contacts during the first half cycle. These breakers, however, are rated on the basis of average current in the three phases, and circuits on which they are installed rarely have X/R ratios exceeding 10. This corresponds to an average rms current during the first cycle equal to 1.23 times the symmetrical current. Such breakers may therefore be applied on the basis of 1.25 times the three-phase initial symmetrical current using subtransient reactance and including both synchronous and induction motors.

In calculating the equivalent system impedances, it should be remembered that at low voltages even small impedance values become of importance, and all elements of the circuit, including current transformers, disconnects, switches, bus runs, and lead wires, should be taken into consideration.

Overcurrent Protective Relays. In approximating the settings of overcurrent relays, the fault currents for two conditions should be determined:

1. The maximum initial symmetrical current for maximum connected synchronous capacity as determined by E/X_1 or $3E/(2X_1+X_0)$, whichever is greater, except that, when R_0 is greater than $5X_1$, no consideration need be given to the latter term.

2. The minimum symmetrical current for minimum connected synchronous capacity as determined by $0.866E/X_1$. In particular situations allowance should be made for remote fault locations and fault resistance.

Ground, distance, balanced, and other types of relays require special consideration.

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2. Protector Tubes for Power Systems, **H. A. Peterson, W. J. Rudge, Jr., A. C. Monteith, L. R. Ludwig.** AIEE *Transactions*, volume 59, 1940, May section, pages 282–92.

Some Aspects of the Electromagnetic Field

LEIGH PAGE

IT SEEMS very strange that, although the Greeks were aware of the attractions of electrified and of magnetized bodies as early as the sixth century before Christ, over 2,000 years should have elapsed before anyone showed sufficient scientific curiosity to perform the simple experiments necessary to determine the quantitative law of force. Michell, of Queen's College, Cambridge, in 1750 seems to have been the first to have established the law of force between magnetic poles. Another Englishman, Cavendish, discovered the law of force between electric charges about 1770, but failed to make his work public. The first to publish the results of accurate experiments verifying the inverse-square law of force for both electric charges and magnetic poles, performed with the aid of his newly invented torsion balance, was the French physicist Coulomb in the year 1785. Thus the quantitative foundations of the great science of electromagnetism were laid only a little more than a century and a half ago.

"The rotating armatures of every generator and every motor in this age of electricity are steadily proclaiming the truth of the relativity theory to all who have ears to hear," declares this well-known physicist, who traces the development of electromagnetic theory from the 18th century to the impact of relativity.

At first progress was slow. The phenomena of electrification and of magnetization appeared to be distinct and unrelated, and it seemed only accident—or perhaps a consequence of the three-dimensional structure of the universe in which we live—that the law of interaction should in each case be the same inverse-square law that had been discovered by Newton a century earlier in the field of gravitation. It was not until 1819 that it occurred to Oersted of Copenhagen that the disturbance of a compass needle during a thunderstorm indicated that an electric current affects a magnetic needle. In his subsequent experiments he first placed a needle at right angles to a wire carrying a current, and was disappointed to observe no effect; when, however, he placed the needle parallel to the wire he found that it turned until it was perpendicular, and in opposite senses according as the needle was placed below or above the current. On September 11, 1820, Oersted's discovery was reported at a meeting of the French Academy, and one week later Ampère announced the discovery of the magnetic interaction between current circuits. In a remarkably short time he performed the crucial experiments that led to his celebrated law of force between current elements. While we know today that this law of force is not correct for two isolated current elements, such as two moving electrons, yet it always leads to correct values of the integrated force when applied to closed circuits carrying steady currents.

Progress was now more rapid. In 1831 Joseph Henry in America and Michael Faraday in England discovered independently the electromotive force due to change in magnetic flux. Although Henry's work unquestionably preceded Faraday's, Faraday is accorded the credit for

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this epoch-making discovery on account of his earlier publication. Faraday was led to his investigations by the feeling that electrostatic induction should have a counterpart in the field of current electricity. While he did not find precisely what he had expected, he was observant enough to note the momentary current in the one circuit when the current in the other changed. Although Neumann in 1845 was the first to express Faraday's discovery in analytical form, Faraday had already given a quantitative description of the phenomenon in terms of lines of force, and it is only appropriate that the law describing his great discovery should bear his name.

The final step in the evolution of the equations of the electromagnetic field was taken by Maxwell in 1864. Unlike the discoveries of Coulomb, Oersted and Ampère, Henry and Faraday, which were based on observation and experiment, Maxwell's great discovery was entirely theoretical—the result of careful examination, bold surmise, and correct reasoning. In modern notation, work prior to Maxwell can be summed up in the field equations

$$\nabla \cdot \boldsymbol{D} = \rho \tag{1}$$

$$\nabla \cdot \boldsymbol{B} = 0 \tag{2}$$

$$\nabla \times \boldsymbol{E} = -\frac{1}{c}\dot{\boldsymbol{B}} \tag{3}$$

$$\nabla \times \boldsymbol{H} = \frac{1}{c}\rho\boldsymbol{v} \tag{4}$$

where $\boldsymbol{D}$ is the electric displacement, $\boldsymbol{B}$ the magnetic induction, $\boldsymbol{E}$ the electric intensity, $\boldsymbol{H}$ the magnetic intensity, ρ the charge density, and $\rho\boldsymbol{v}$ the current density, all in Heaviside–Lorentz units. The symbol $\nabla\cdot$ represents the divergence, $\nabla\times$ the curl, and a dot over a letter the time derivative.

The first two of these equations express the results of Coulomb's work, equation 3 is Faraday's law for the induced electromotive force due to change of magnetic flux, and equation 4 is Ampère's law for the magnetic field produced by a current. Maxwell's great contribution sprang from his observation that these equations fail to satisfy the equation of continuity, which must hold if electricity is conserved. To make the field equations consistent with this essential relation, he found it necessary to replace equation 4 by the Ampère–Maxwell law

$$\nabla \times \boldsymbol{H} = \frac{1}{c}(\dot{\boldsymbol{D}} + \rho\boldsymbol{v})$$

Maxwell's innovation makes Ampère's law in empty space the exact counterpart of Faraday's law. It demands the presence of a magnetomotive force whenever there is a change in electric flux. Why, then, is not this magnetomotive force observable experimentally with the same facility as the electromotive force described by Faraday's law? The answer, of course, is that nature provides us with no methods of detecting a magnetomotive force comparable in delicacy with those we use for measuring an electromotive force.

Maxwell's correction to Ampère's law led to a startling consequence. The second-order differential equation for *one* of the field intensities in empty space, obtained by eliminating the *other* field intensity from the first-order equations, proved to be the equation of a wave traveling with a velocity equal to the ratio c of the electromagnetic to the electrostatic unit of charge. It had already been noticed that this ratio was identical, within the limits of experimental error, with the velocity of light. The electromagnetic theory of light, confirmed subsequently in so many of its intricate details, was inevitable. Today the gamut of explored electromagnetic waves extends from the radio waves of several kilometers length through the infrared, the visible octave, the ultraviolet and X-ray region, the gamma rays emitted in radioactive disintegrations, to the cosmic rays. Maxwell could not envisage the immense wealth of the field to which he had opened the gate. He even doubted that it would be possible to construct apparatus delicate enough to produce and to detect the electromagnetic waves demanded by his theory. In fact this was not accomplished until Hertz performed his historic experiments of 1888.

The four field equations, in the form given them by Maxwell, describe only one aspect of the phenomena of electromagnetism. They specify the electric and magnetic fields produced by any assigned distribution of charge and current. But it is equally important to know the forces or torques exerted on charges or currents placed in a field produced by some outside agency. This information is contained in the force equation, which was perhaps best formulated by the late Dutch physicist, H. A. Lorentz. The four field equations and the force equation, together with such constitutive relations between $\boldsymbol{D}$ and $\boldsymbol{E}$ on the one hand and between $\boldsymbol{B}$ and $\boldsymbol{H}$ on the other as are necessary to describe the properties of a material medium, and Ohm's law for the relation between current density and electric field intensity, constitute the complete set of electromagnetic equations.

Velocities appear in these equations only in connection with the motion of charges; that is, electric currents. There is no reference to motion of a field. The concept of moving lines of force of a magnetic field, producing an electromotive force when they cut a conductor, so much used in teaching elementary physics and electrical engineering, is quite extraneous to Maxwell's theory. Of course this concept, when applied to a *closed* circuit, will always lead to correct results for the *integrated* electromotive force, even though it may lead to an erroneous *distribution* of electromotive force around the circuit, for in this case it gives just the time rate of change of flux. But this concept may lead to utterly wrong conclusions in the case of an open circuit. The classical example is that of a cylindrical magnet (Figure 1) mounted so that it may be given a spin about its axis of symmetry *SN*. Let a piece of wire *AB* be placed at right angles to the

magnet near its center on a line passing through the axis of the magnet. Then, if its field rotates with the magnet, we would expect on the moving-line concept that there would be an electromotive force along the wire when the magnet rotates and the wire is stationary, and none when the two rotate together. The electromagnetic equations, on the contrary, predict the exact opposite in each instance. In 1912 Barnett performed this experiment, and completely disproved the moving-line concept. In a recent book Cullwick attempted to show that the moving-line concept would lead to correct results if the charges produced on the rotating conductor were taken into account, but his analysis was faulty, as he has since admitted.

The moving-line concept cannot be saved by assuming that a magnetic field follows the magnet producing it without rotating, for even this assumption, when we integrate the effects due to all the filaments comprising the rotating magnet, leads to a residual, if smaller, electromotive force along the stationary wire.

It seems unfortunate, therefore, that a concept, wrong in theory and disproved by experiment, should be so commonly taught and used, particularly in view of the fact that the correct concept is equally simple.

The electromagnetic equations distinguish two fundamentally different types of electromotive force. First we have the electromotive force described by Faraday's law (equation 3). This is the electromotive force produced by a changing magnetic flux through a circuit *fixed* in the observer's inertial system. It is exemplified by the transformer. The changing magnetic field is, of necessity, accompanied by an electric field, of which the lines of force form closed loops and therefore give rise to an electromotive force around a properly oriented closed circuit. It must be emphasized that this electric field exists in the observer's inertial system whether a conducting circuit is present or not. It is a field very different from that produced by a static distribution of charges, in that it is not expressible as the gradient of a single-valued scalar potential function.

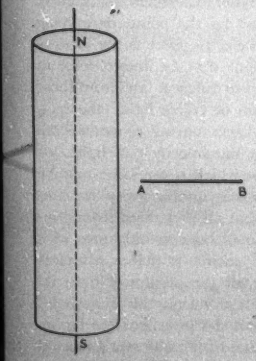

Figure 1

The second type of electromotive force, differentiated from the first by the addition of the adjective "motional," has its origin in the second term of the force equation. This important electromotive force is exhibited in the rotating armature coils of a generator. It comes into being whenever a conducting wire *moves relative to the observer* through a magnetic field. The electric field in the inertial system of the moving wire, which it implies, is nonexistent in the observer's inertial system, as is evident from the fact that no electromotive force is discernible when the wire is at rest relative to the observer.

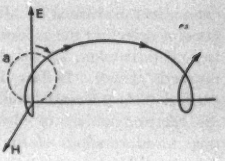

Figure 2

These characteristics of motional electromotive forces are leading us straight to the relativity theory. Before discussing the impact of that theory on the subject of electromagnetism, let us examine another simple electromagnetic phenomenon illustrating the fact, just brought out in connection with motional electromotive forces, that, although an observer in *one* inertial system may be aware of an electric field, an observer in *another* inertial system at the same place and at the same time may find no electric field at all. Consider a charged particle, such as a proton, which is projected into a uniform magnetostatic field in a direction at right angles to the lines of force. It will describe a circular path about the magnetic lines of force, with an angular velocity that is *independent* of the initial linear velocity or of the radius of the orbit. It is this property of its motion that makes possible the operation of the cyclotron.

Now suppose that in addition to the uniform magnetostatic field $\boldsymbol{H}$ we have present a uniform electrostatic field $\boldsymbol{E}$ at right angles as in Figure 2. Then the path of the proton is a cycloid generated by a rolling circle lying in a plane perpendicular to the magnetic lines of force and advancing in a direction at right angles to both fields with a constant speed depending only on the ratio of the field intensities. Let us examine the motion of the proton, now, from the point of view of an observer in an inertial system moving along with the center of the rolling circle *a*. To him the path is a circle about the magnetic lines of force. The effect of the electric field has vanished; indeed, he has no choice but to conclude that no electric field exists in his inertial system.

Even simpler are examples in which a magnetic field is annihilated by a change in the observer's state of motion. Consider a charge moving with constant velocity relative to one observer's inertial system. On account of its motion it constitutes a current element, and gives rise to a magnetic field. But to another observer located in the inertial system of the charge there is no motion and no magnetic field.

The special relativity theory enunciated by Einstein in 1905 does not say that all motion is relative. It asserts that the laws of nature are the same when referred to one inertial system as when referred to any other. Contrary to popular belief, the relativity theory is *not* based fundamentally on the negative result of the optical

experiment performed by Michelson and Morley in the hope of detecting the motion of the earth relative to a hypothetical ether. It is a direct outgrowth of electromagnetic theory. In fact, Einstein's original paper is entitled "Zur Electrodynamik Vewegter Körper" (On the Electrodynamics of Moving Bodies). The space-time transformations of the theory had already been discovered by Lorentz as a result of his work on the electromagnetic theory of light in moving media. Einstein's great contribution was a new interpretation of these transformations.

Consider two inertial systems S and S', the second of which is moving relative to the first with a velocity v directed along the X axis. The relativity theory tells how to find the electromagnetic field in S' if we know that in S, or vice versa. For simplicity I shall confine myself to fields in empty space. Then, designating the field components in S' by primes,

$$\begin{aligned} E_x' &= E_x & H_x' &= H_x \\ E_y' &= k\{E_y - \beta H_z\} & H_y' &= k\{H_y + \beta E_z\} \\ E_z' &= k\{E_z + \beta H_y\} & H_z' &= k\{H_z - \beta E_y\} \end{aligned}$$

where $\beta \equiv v/c$ and $k \equiv 1/\sqrt{1-\beta^2}$, c being the velocity of light.

First we should like to know the invariants of these transformations; that is, the quantities which are the same to both observers. They are $\boldsymbol{E}\cdot\boldsymbol{H}$ and $E^2 - H^2$. The first tells us that if $\boldsymbol{E}$ and $\boldsymbol{H}$ observed in one inertial system are perpendicular, as in a wave front, they are perpendicular in all. The second tells us that the difference of the squares of the field strengths is the same in all inertial systems. Note that this does not represent the energy of the field, which is given by the sum of E^2 and H^2. In an electromagnetic wave, for instance, E and H are equal in all inertial systems. If the wave is advancing in the X direction, both E and H, as well as the frequency, are less as observed in S' than as observed in S.

If E and H are perpendicular and unequal we can always eliminate the smaller by giving the observer an appropriate velocity. Let E be along the Y axis and H along the Z axis. Then it is clear from the transformations for the components that the requisite velocity is $c(E/H)$ to annihilate E or $c(H/E)$ to annihilate H.

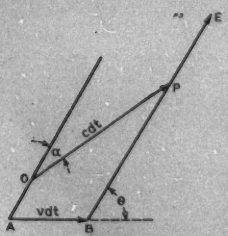

Figure 3

One can multiply examples. A simple case is that of a long charged parallel plate capacitor in S with the plates perpendicular to the Y axis. In S we have the electric field E_y and no magnetic field. In S', however, we have the stronger electric field $E_y' = kE_y$ and the magnetic field $H_z' = -k\beta E_y$. The strengthening of the electric field is due to the Fitzgerald–Lorentz contraction which makes the charge density on the plates greater in S' than in S, and the magnetic field is due to the current sheets consisting of the moving charged plates.

This analysis results in the recognition that there is no meaning to the assertion that here and now there exists a specified electric field and a specified magnetic field. All that can be said properly is that there exists a certain electromagnetic field: its resolution into electric and magnetic parts depends upon the state of motion of the observer.

Although I have criticized the *wrong* use of the representation of an electromagnetic field by lines of force, I do not wish to give the impression that this representation is not useful, and indeed highly significant. Faraday's introduction of this geometrical concept was perhaps one of the most important of his many contributions to science. In fact, by means of this concept we are able, with the aid of the relativity theory, to explain in a very fundamental way *why* a moving charge or current gives rise to a magnetic field and further actually to deduce both the Ampère–Maxwell law and Faraday's law from the simple inverse-square relation of Coulomb. If the relativity principle had been recognized in Coulomb's time, the experimental investigations of Oersted and Ampère, Henry and Faraday, would have been unnecessary.

Since electric charges exist in nature and are conserved, whereas magnetic charges do not exist at all, lines of electric force are far more fundamental than lines of magnetic force. In fact, the number of lines of electric force diverging from a given charge remains the same whatever we do to the charge. On the contrary, a charge at rest in the observer's inertial system has no magnetic field at all. When it is put into motion a previously nonexistent magnetic field is created.

The principle of relativity requires that every law of nature shall be the same and contain the same constants, no matter to what inertial system it is referred. Hence, if there exists a velocity law for the points or moving elements of which a line of electric force is the locus—and there is no reason to think that the lines of force in even a static field are subject to different laws from those in the wave front of a beam of visible light—the relativity theory requires that these moving elements shall move in straight lines with the velocity c of light, for this is the only velocity law which is the same relative to all inertial systems. One may question why one cannot equally well conclude that all shots fired from guns and all stones thrown by small boys should move with the velocity of light. The answer is that a complete velocity law does not exist for the motion of material particles. To be sure, a partial velocity law does hold, for we find that material particles in a field-free region move in straight lines relative to the observer's inertial system. Therefore the relativity principle requires that

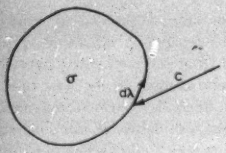

Figure 4

they shall move in straight lines relative to all inertial systems. But nature imposes no restriction on the speed of a material particle, other than that it shall be less than the velocity of light.

Consider first a point charge permanently at rest in the observer's inertial system. As its field is static, the motion in this case must be along the lines of force, and, in order to avoid teleological difficulties, we must imagine the charge itself to be a source of lines of force moving away from it with the velocity of light.

Next consider a charge in uniform motion relative to the observer. As it carries its field with it, the velocity $\mathbf{c}$, with which each line of electric force is moving, must make an angle with the line itself, which is greater the greater the velocity of the charge. The vector $(1/c)(\mathbf{c}\times\boldsymbol{E})$ represents exactly, both in magnitude and direction, the observed magnetic-field intensity. We do not make any assumption in identifying this vector with $\boldsymbol{H}$, because $\boldsymbol{H}$ is measured as a force or torque on some magnet or current, and when we have deduced the complete set of electromagnetic equations, we find a force depending on $(1/c)(\mathbf{c}\times\boldsymbol{E})$ in exactly the same manner as the force in the classical formulation depends on $\boldsymbol{H}$. In fact, it is quite simple to show that the vector $(1/c)(\mathbf{c}\times\boldsymbol{E})$ in the field of an elementary charge moving with constant velocity $\boldsymbol{v}$ small compared with that of light is identical with the magnetic field as specified by the modern version of Ampère's law. Let A (Figure 3) be the position of the charge e at time t and B its position at time $t+dt$. Then $OP=cdt$ and $AB=vdt$, and the vector $(1/c)(\mathbf{c}\times\boldsymbol{E})$ at P is a vector of magnitude $E\sin\alpha$ directed out from the page. But $c\sin\alpha=v\sin\theta$ from the figure and in the Heaviside–Lorentz symmetrical units which are used here

$$\left|\frac{1}{c}\mathbf{c}\times\boldsymbol{E}\right|=E\frac{v}{c}\sin\theta=\frac{ev}{4\pi cr^2}\sin\theta$$

As the current element equivalent to ev is idl, where i is the current and dl an element of the circuit, we have finally

$$\left|\frac{1}{c}\mathbf{c}\times\boldsymbol{E}\right|=\frac{idl\sin\theta}{4\pi cr^2}$$

which is the usual form of Ampère's law in these units for a current element. The more familiar form of this law in electromagnetic units is obtained by multiplying by $4\pi c$.

A detailed analysis, first published 27 years ago, shows that Ampère's law, including Maxwell's correction, is nothing more than the kinematical equation of motion of the lines of electric force constituting the field of a charge. The proof is quite simple. Consider a bounded surface σ (Figure 4) *fixed* in the observer's inertial system. If N is the electric flux through this surface, the time rate of increase of electric flux is

$$\frac{dN}{dt}=\int_\sigma \dot{\boldsymbol{E}}\cdot d\boldsymbol{\sigma}$$

The part of this increase due to lines of force crossing the periphery from outside to within is

$$\oint \boldsymbol{E}\cdot d\boldsymbol{\lambda}\times\mathbf{c}=\oint \mathbf{c}\times\boldsymbol{E}\cdot d\boldsymbol{\lambda}=\int_\sigma \nabla\times(\mathbf{c}\times\boldsymbol{E})\cdot d\boldsymbol{\sigma}$$

and the part due to charge of volume density ρ crossing the surface with velocity $\boldsymbol{v}$ is

$$-\int_\sigma \rho\boldsymbol{v}\cdot d\boldsymbol{\sigma}$$

Adding these,

$$\frac{dN}{dt}=\int_\sigma \{\nabla\times(\mathbf{c}\times\boldsymbol{E})-\rho\boldsymbol{v}\}\cdot d\boldsymbol{\sigma}$$

Equating these two expressions for the time rate of increase of flux, and putting $\boldsymbol{H}$ for $(1/c)(\mathbf{c}\times\boldsymbol{E})$ we have the Ampère–Maxwell law

$$\nabla\times\boldsymbol{H}=\frac{1}{c}\dot{(\boldsymbol{E}}+\rho\boldsymbol{v})$$

This simple deduction does not even require the use of the space-time transformations of the relativity theory.

Faraday's law is deduced with equal rigor, although not so directly. Since any field, however complicated, is the resultant of the individual fields produced by the elementary charges and currents present, we can describe, in terms of lines of electric force moving with the velocity of light, the field of an elementary charge having any arbitrary velocity and acceleration relative to the observer's inertial system. Making use of the space-time transformations of the special relativity theory, we prove that $\boldsymbol{E}$ and $\boldsymbol{H}$ can be expressed in the forms

$$\boldsymbol{E}=-\nabla\phi-\frac{1}{c}\dot{\boldsymbol{A}}$$

$$\boldsymbol{H}=\nabla\times\boldsymbol{A}$$

in terms of a scalar potential ϕ and a vector potential $\boldsymbol{A}$. As any field may be regarded as the resultant of elementary fields of the type considered, these equations must hold for all electromagnetic fields.

Faraday's law follows immediately from this pair of relations. Taking the curl of the first and the time derivative of the second we obtain

$$\nabla\times\boldsymbol{E}=-\frac{1}{c}\dot{\boldsymbol{H}}$$

The transformations already stated for finding the electric and magnetic vectors in one inertial system from the known values of the field intensities in another are especially important, for it is by means of them that we deduce the term in the force equation specifying the

force exerted by a magnetic field on a current. This term is responsible for the action of every generator or motor with a rotating armature.

These transformations are deduced quite easily from the concept of lines of electric force moving with velocity $\mathbf{c}$. In the deduction, however, the relativity theory plays a very essential role. Consider a segment OP (Figure 5) of a line of force at time t in the observer's inertial system S, all points of which are moving with the velocity $\mathbf{c}$. Here the two ends O and P of the segment are pictured at the *same* time t. Viewed from some other inertial system S', however, the events O and P are *not* simultaneous. If the time in S' at O is t', the time at P is less than t', if S' is moving to the right relative to S. At time t', P has moved up to Q. Hence the segment of the line of force at time t' in S' is OQ instead of OP. This relativistic aberration of the field accounts for the terms in $\boldsymbol{H}$ in the transformations of the components of $\boldsymbol{E}$.

The force equation is obtained immediately from the transformations for the components of $\boldsymbol{E}$, since we can always find an inertial system in which a moving charge is momentarily at rest. In that system the force on the charge is just the product of the magnitude of the charge by the electric field intensity. By transforming to the observer's system we find the force on a charge in motion, including as one term the force on a current element in a magnetic field.

The foregoing is sufficient to show that the rotating armatures of every generator and every motor in this age of electricity are steadily proclaiming the truth of the relativity theory to all who have ears to hear. If the Galilean–Newtonian concept of space-time were valid, many of my readers would be out of a job.

The representation just discussed is particularly useful in picturing graphically the propagation of electromagnetic waves from an accelerated charge. If a charge is executing linear harmonic vibrations, for instance, it is a simple matter to construct, with any degree of accuracy desired, the wavy lines of force of its field. In fact, the problem is identical with that of constructing the locus of the water particles shot out of a hose, the nozzle of which follows the motion of the charge. Figure 6 shows the evolution of such a line of force.

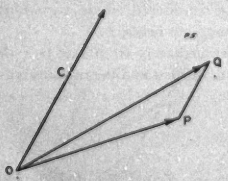

Figure 5

We have been educated to accept the dogma that nature provides us with electric charges, but with no magnetic charges. It is a simple matter to write down the field equations and the force equation which would hold in a world in which are present both electric and magnetic charges. On examining these equations we find that a simple transformation allows us to reduce them to the classical electromagnetic equations, provided, and only provided, that every charged particle carries electric and magnetic charges in the *same* ratio. With this provision, then, there is no electromagnetic experiment that can distinguish between our current concept of nature and one in which all charged particles are conceived to carry both electric and magnetic charges in a constant ratio. The assertion that only electric charges exist in nature is not a conclusion derived from observation and experiment, but a result of the *terms* in which we have chosen to interpret our experiments. Of course our usual interpretation is simpler than any other, and therefore more convenient.

I hope it is not inappropriate to emphasize, in conclusion, the esthetic qualities of electromagnetism. Of course we are aware that electromagnetic theory fails to cover the whole domain of physical phenomena. The theory breaks down when it is applied to atoms and molecules; that is, to phenomena on the ultramicroscopic level. Here the still mysterious and imperfectly understood quantum mechanics holds sway. But in the field in which it is competent, electromagnetic theory possesses a beauty of form and of interpretation never approached by any physical theory proposed before or since.

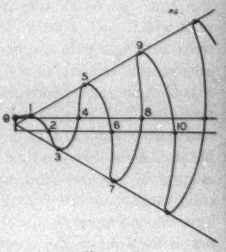

Figure 6

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New Engineering and a New Industry

M. M. SAMUELS
FELLOW AIEE

NO ONE has yet succeeded in educating the public in what an engineer is and what he does, but we can say definitely what is *not* engineering. Anything that does not rest on a foundation of physics and mathematics is decidedly not engineering. Following the basic idea that engineering must rest on a foundation of physics and mathematics I will indulge in the attempt to establish two new definitions:

1. Rural-electrification engineering.
2. Electroagricultural engineering.

RURAL-ELECTRIFICATION ENGINEERING

Rural-electrification engineering deals with the power supply to rural areas, including bringing power to a rural project and distributing it in the project to the consuming devices. It includes all problems involved in the study of the relative reliability of service of the different methods of power supply, relative costs, overcurrent protection, voltage regulation, protection against overvoltages, and similar problems that are definitely established as engineering.

This article reviews the present status of rural-electrification engineering, which has become established during the past few years, and points to the beginning of what the author terms "electroagricultural engineering," which deals with the applications of electricity on the farm. The author predicts that a new industry will be established to produce the equipment needed for these applications.

About three years ago there was no rural-electrification engineering. A year ago we were just about in the process of creating one. Now the first chapter of rural-electrification engineering has been completed, the second chapter about half completed, and the third chapter just started. A pamphlet[1] known as "Rural Electrification Administration Technical Standards Bulletin No. 4" was issued in August 1941, and has already secured for itself the recognition of the profession as the first chapter of rural-electrification engineering. It covers what may be called the "ampere problems" in rural circuits. It deals with the computation of short circuits, the rationalizing or sectionalizing of the system, and the selection of protective devices against overcurrent. As has been the case throughout the history of electrical engineering, so here the analytical work resulted in new inventions and new developments. As the analytical work progressed it was found that certain devices required to solve the problems did not yet exist, and young engineers proceeded to invent them.

The second chapter might be called the broad problem of communication related to rural circuits. During the 1941 AIEE winter convention, a joint paper[2] by Rural Electrification Administration engineers and Bell Telephone Laboratories engineers was presented, covering the subject of telephone interference on rural circuits. This too is recognized as the basic paper on the problem and forms a beginning of the second chapter of rural-electrification engineering. The problem of carrier current has been covered in various ways and is still in the process of development. So is direct radio communication and its numerous diversifications.

The third chapter, that relating to voltage problems, is now in the process of being prepared. We started only a very short time ago and are now following the usual course of conservative engineering by first starting with cases. After we will have solved a number of cases we no doubt will generalize; we then hope to have a competent text on voltage-regulation problems specifically relating to rural circuits. No doubt the analytical work will bring out the need for new devices, and undoubtedly young engineers will invent them.

A thorough study is now under way covering the relationship of the main conductor and the neutral conductor. This is a broad problem involving, first, the question of whether the neutral conductor should be at the top of the pole or underneath the main conductor and, second, the possibility of eliminating the neutral conductor altogether. Here, too, we follow the engineering procedure of first exhausting all analytical possibilities and then proceeding to rational testing.

Numerous new developments and inventions have been brought about in the course of the analytical study of short-circuit conditions. It was found that the so-called three-shot fuses can no longer be considered modern and that circuit breakers are required to take their place. A year ago there was only one type of sectionalizing breaker on the market. Three types are now being used experimentally, about 75 of each. About 3,000 of the older type of breakers were installed during the year and all reports indicate that they are

Based upon an address presented at the fall meeting of the American Society of Agricultural Engineers, Chicago, Ill., December 3, 1941. The original address was prepared and presented before Pearl Harbor. Some of the developments predicted therefore have been delayed by subsequent restrictions on materials.

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contributing to the reduction of the number and duration of outages. It is reasonable to assume that within a short time the newer types of breakers will have established themselves on the market as standard articles.

Four REA projects are now equipped with carrier recording devices invented and developed by two young REA engineers and put into production by the Stewart-Warner Corporation. When a three-shot fuse or a sectionalizing breaker goes out a record is made instantaneously on a tape in the superintendent's office. Similarly, when service is restored, a record is made on the same tape. This tape not only gives immediate notice of failure and restoration, but also leaves a permanent record of all outages. It is hoped that within the next year 100 REA projects will be equipped with these devices.

Progress has been made in the development of two-way and three-way carrier communication over REA power lines. A "hot stick" has been built and tried out which makes it possible for a lineman to talk to headquarters from any place along the line by merely throwing the "hot stick" over the line. This has not yet been permanently installed anywhere, but it is hoped to equip three projects with this instrument experimentally very shortly.

The study of short-circuits and co-ordination of protective devices led to the conclusion that it is advisable to have circuit breakers instead of fuses in the farm homes. These circuit breakers must have certain definite characteristics to co-ordinate with the system. As a result, all new REA projects are equipping the farm homes with circuit breakers. In addition to better co-ordination of protection, it is an enormous convenience to the farm.

The problem of properly protecting a rural power system against short-circuits and lightning is by no means solved. There is no real protection for the primary side of a distribution transformer. But I feel optimistic enough to predict that very soon there will be a very small circuit breaker for this purpose, at a price not much higher than that of a fuse. I also feel optimistic enough to predict that soon there will be an automatic reclosing circuit breaker for the low-voltage side of the small distribution transformer, which will be sufficiently cheap for the purpose.

Industrial loads on REA lines have been growing by leaps and bounds and each industrial addition calls for a competent engineering analysis relating to voltage regulation and protection. As of January 1, 1941, there were reported 5,365 industrial and commercial consumers on REA lines, served by a total transformer capacity of over 106,000 kva. There is little doubt that the provision of electric power in areas where small industries are located filled a long-felt need. It is possible that a large proportion of these industrial loads did not exist or could not have existed prior to the availability of electric power. This survey shows clearly what has been accomplished in so short a time by spontaneous individual initiative in the way of decentralization of industry and stimulation of individual enterprise through the existence of a government-financed activity. It is a mere indication of what can be accomplished along the line of decentralization and migration of industries to rural areas with the attendant benefits both to the farm and to the industrial worker.

Another indication of the engineering problems involved in rural-electrification engineering is the enormous growth of energy used on the various REA projects. In 1939, REA systems purchased 152,398,000 kilowatt-hours for which they paid $1,843,962; in 1941, they bought 735,378,000 kilowatt-hours for $7,377,755. Thus, during the two-year period the increase in total kilowatt-hours purchased was not far from 400 per cent and the increase in money paid out was over 300 per cent.

Technical standardization without stagnation has been carried forward by REA successfully. The technical standards committees and their procedure, in the short time of their existence, have established an enviable reputation for themselves in the industry and in the engineering profession for competence, honesty, and progress. The record shows that as of November 1, 1941, the committees had cleared 598 items submitted by 68 manufacturers, unanimously approved 350 items, and unanimously rejected 83 items, the latter submitted by 23 manufacturers. Not a single complaint is on record. These committees are unique in governmental procedure.

Thus, within a short time rural-electrification engineering has become a respectable branch of engineering in general. It is hoped that from now on the engineering schools will begin to cover this branch in their courses and engineering societies will give it the time and space to which it is entitled.

ELECTROAGRICULTURAL ENGINEERING

Electroagricultural engineering may be defined as that branch of engineering which deals with the application of electricity on the farm. There is no evidence yet of even the beginning of a foundation of physics and mathematics for this branch of engineering. So far there is not yet in existence a crystallization of questions or a statement of problems in this field to be subjected to solution by engineering methods. There is hardly any competent accumulation of pertinent engineering data.

Some time ago it became evident that young men were leaving the farm and others were going into the army, throwing the burden of production on the women and the aged. It also became evident that the United States would have to feed a large army at home, other peoples' armies abroad, and, eventually, a good portion of the civilian population of Europe, Asia, and Africa. It was important to find out with how much less man power full production can be secured on an electrified farm than on an unelectrified farm. It was a great dis-

appointment to discover that no adequate statistical data were available.

During the past year an effort has been made to secure from recognized authorities some pertinent statements on the relative importance of different durations of service interruptions of the several hundreds of possible applications of electricity on the farm. It was hoped that this would serve as a foundation for rationalizing the design of rural circuits. A list of some 300 items was prepared and sent out to six outstanding authorities in the field. It was thought that there would be a unanimous opinion in regard to many of the questions and that it would be possible to reduce the items calling for study to a relatively small number. But the six sets of answers show a bewildering diversity of opinion, even as related to items that might be considered self-evident. The great diversity certainly reveals the fact that no systematic study has ever been undertaken, but it is never too late to get started.

A visit to various agricultural colleges brought out the fact that many competent and serious-minded men, working under great handicaps, have developed some fine and useful equipment only to be discouraged because they could not interest any manufacturer to put it into production so that every farmer in the country could get the benefit of it. The best they could do was to send a set of prints or a booklet to the individual farmer and invite him to build it himself. However, if a farmer were to build himself all the gadgets for which instructions are sent to him, he would have little time for farming. But what else could those hard working, competent men of science do? The electric brooder will serve as a good illustration. At every agricultural college visited, someone had a new electric brooder which he considered superior to any other. Practically every agricultural engineer I met outside the colleges likewise had a new brooder, better than all others. In one of the colleges, when I was introduced to the professor, I asked him offhand to show me his new electric brooder. His surprised reply was: "How did you know that I had one?" Now each of these men has the welfare of the chicken sincerely at heart. Every one undoubtedly made some real worth-while improvement. All these improvements combined, should result in a range of standardized brooders that will meet practically all conditions. I do not mean that we then should stop improving. Every new automobile model has some improvements over the previous model. Yet we go ahead with quantity production without waiting for all possible improvements. When the time comes to go into production we say that other improvements will have to wait for the next model.

It is important that we have a clear picture of this bewildering and uneconomic situation. We must take the devices away from the inventors and place them into the hands of the manufacturers to be produced in quantity, so that they can be placed into the hands of every farmer. When I say "take them away" I do not mean that we should permit manufacturers to steal inventions and developments. On the contrary, it is of extreme importance that every research institution try to find some means of protecting the invention either for the benefit of the inventor or the institution. In either case it is important to make certain that the farmer will not be charged exorbitant prices.

Thus, both a new branch of engineering and a new industry will have to be created. Until now manufacturers could not be expected to spend money on new electrical developments to be used by individual small farmers. There was no ready market. But the situation has changed. With the hundreds of thousands of farms electrified in the last few years, with the group-purchase plan developed by REA which permits co-operative quantity purchases, a ready market is opening up for many new items for which no market was in sight a few years ago.

Those who have had experience in bringing out new ideas will realize that these new developments do not just happen. Every time anyone tries to bring out a new idea or a new device he encounters two kinds of opposition. First, there is the general inertia of the human mind. Most people do not like new ideas.

The other opposition consists of short-sighted manufacturers who try to force a customer to use what they make instead of making what the customer needs, or even anticipating and developing what he will need. However, a few manufacturers have had the courage to spend money on pioneering new developments, realizing that a new market is opening up and that specific equipment is needed for this market. In the long run, a big volume of business is bound to be their reward, and in some cases already is their reward.

Another important point is that in both rural electrification and electroagriculture we, in the REA, accomplished what we did without indulging in the luxury of establishing new research laboratories. We preferred to limit our own activity to invention and stimulation and to depend on all existing research facilities in colleges, governmental institutions, and manufacturing establishments to do the developing. This is more than any one laboratory, no matter how heavily endowed, could possibly do. The wisdom of this policy, I believe, is demonstrated by the fine results we had in such a short time.

Six years ago we had no rural electrification; today we have it. Even a year ago we had no electroagriculture; today we have the beginning of this new engineering. I feel that we are justified in hoping that, in spite of the efforts of some short-sighted manufacturers to force time backward, America still has enough progressive manufacturers that will soon bring out enough new devices to make the fully electrified American farm a reality.

Hand in hand with the development of this new industry, there must be an electroagricultural engineering

on a foundation of physics and mathematics. No such thing is yet in existence. What is being done now is not yet engineering. It is not even a trade. It is more like the amateur age in radio. But, just as out of the amateurs in radio there eventually emerged a radio engineering and a radio industry, so it is hoped that out of the present amateur age of electroagriculture there will soon emerge a new electroagricultural engineering and a new electroagricultural industry.

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Vocational Education and the War

ALONZO G. GRACE

The recognized defects in the American system of public education will not be remedied by creating new agencies, but by the intelligent co-operation of educators and the public in the development of an educational program that will teach the citizens of the future how to live and how to earn a living, says a state commissioner of education, who points out that a trained citizenship is our first line of defense.

IT IS difficult in these trying days to comment on the long-term implications of education and in particular on the trends affecting vocational education. Our first thought necessarily must be directed toward the adjustment of an educational system to meet the requirements of total war; that is, the training of a labor supply, development of health and physical-fitness programs, translation of the war aims of the United States and the Allies into terms that can be understood by children and youth, the development of co-operative programs with the Army, the Navy, the Marines, Civil Aeronautics Administration, assistance in rationing procedures, enlightenment of the public with respect to the meaning of basic economic concepts, such as inflation, and a multitude of essential wartime activities.

One of Hitler's most powerful weapons is no secret weapon. His is an organization of a nation's youth—the mobilization of youth and its enthusiasm behind the supreme nationalist aim to restore the strength of Germany and to establish the Socialist State universally. Nazi organizations such as the *Jungvolk* (young folk), Hitler *Jugend* (Hitler youth), and *Bund Deutscher Maedel* (league of German girls) take in hand youngsters between the ages of 10 and 18. In the youth organizations these recruits are raised on Nazi propaganda and a thorough physical-fitness program. They are encouraged to become enthusiastic about sports, such as glider flying, model-airplane building, marksmanship, and the elementary principles of seamanship. They wear uniforms, go on long hikes, and learn to live in the open air. The first procedure in the totalitarian state has been a drastic reorganization of the educational system to provide the kind of members desired for the ultimate purpose of the state.

The American educational system is based upon a totally different idea. The control of educational opportunity in the United States is not centralized. The educational system is organized on a local basis, for in the United States the community is regarded as the cell of democracy. The importance of local initiative and responsibility is a matter not to be regarded lightly as we face the future. Through state leadership, service, research, and planning, with Federal financial assistance and leadership, and with local willingness to provide adjustments, a more effective educational opportunity is on the horizon.

With the understanding that the American school and college system is geared into the war effort, this article considers some reasons for educational lag, important trends affecting the future of vocational education, and some of the needs in the field of education generally.

SOME REASONS FOR EDUCATIONAL LAG

The school has been criticized for failure to produce a nation of skilled workers, for developing false ideals concerning the ultimate objective of living, for failure to develop good work habits in youth, and for many other reasons. It has become common practice to attribute many of our present difficulties to a faulty educational system. Granted that America has an unwieldy and ineffective system of local administrative organization; that many state departments of education do not exhibit inspiring leadership, acceptable scholarship, pertinent research, or effective service; that educators have been slow to face realistically the problems of youth; that the secondary-school program has been unduly academic in nature; that the school program is a series of unrelated

Essential substance of an address presented at the AIEE North Eastern District meeting, Schenectady, N. Y., April 29–May 1, 1942.

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compartments; that these and many other criticisms of public education are just and valid—the remedy does not lie in the creation of other agencies to secure the needed changes. The best method of improving the school system and the best guarantee that the emerging product will represent social competency are to be found in the willingness of all elements to aid the existing educational system to perform the functions for which it was created. This is a major issue at the moment and no doubt will continue to challenge the disposition and vision of all concerned for some time to come.

There can be but one system of public education in the United States and that system should continue as it has for over 300 years—a responsibility of the several states, which with few exceptions delegate the actual conduct of the schools to the people of the state through local boards of education. The solution to our problem does not lie in a superstate or superfederal government that will absorb the functions of units closer to the people. While it may be admitted that many units of local government conceived during the pioneer era in the evolution of American democracy no longer are able independently and separately to provide all the services now required for the security of the people, the solution does not lie in the creation of or transfer to units far removed from the grass roots. Without the sustained interest of the governed, efficient administration and effective establishment of policy can be but partially attained.

Instead of attempting to place the responsibility for failure to avert many of our problems, our thoughts must be turned to the development of a constructive program. It is essential, therefore, that every state undertake the appraisal and evaluation of its own school system and that the wisdom and intelligence of its citizens and professional educators be used to the maximum in the development of a program that will teach people how to live as well as how to make a living.

Whatever be the lag in public education, it must be said that educators have not been wholly responsible. The following illustrate some of the factors involved:

1. *The Cost in Dollars and Cents.* It is cheaper in terms of dollars and cents for a school system to employ a teacher for 40 pupils in an academic course than to provide one teacher for 15 boys or girls who desire to learn a trade or to learn how to make a living.

2. *Parental Desire.* Many parents struggle throughout life in order that their children may not have to endure the hardship, the sacrifice, or unpleasantness that circumscribed their lives. False values have been placed on certain types of training.

3. *Prestige Value.* There is a prestige value attached to the college-preparatory curriculum that impedes the real job of education. The real weakness in public education emanates from the prevailing belief that other educational opportunities are devices designed to take care of those who indicate lack of interest, or fail, in the college-preparatory curriculum. If we would build a classless society, the social prestige attached to specific curriculums must be eliminated.

4. *Diplomas, Certificates, Degrees.* Business and industry have made the diploma from high school or college a prerequisite for employment. So long as those who employ regard the diploma of graduation as an index of competency, just so long will individuals fail to meet the requirements for employment. The criteria for employment should be "What can you do" and "How well can you do it" not "What kind of a diploma do you have" and "Where did you get it."

5. *Sacrifice and Work.* It is essential that the American people as a whole begin to feel a sense of sacrifice for the welfare of our country. Let us not believe that we can live without enduring hardships or that we can ease our way out of the trying situations confronting us. The utmost sacrifice will be necessary in the years to come if this nation survives.

Equal respect for all kinds of labor, physical and mental, honestly done, is recommended, but social barriers against the hand workers are set up. The office worker, for no good reason, is placed on a higher social level. This tendency must be corrected if there is to be a change in the school organization and curriculum. The best way would be to make honest statements concerning the qualifications of graduates.

We should be under no illusion concerning the training of the citizens of tomorrow. Vocational education and guidance do not create jobs. The proper diagnosis of the talents of the individual and the ability to ascertain those areas in which he can make the greatest contribution to his own happiness and to the security of society will at least give one a passport to a job. Training for the work of the world and for the work that each one is best able to do is the first essential in social security and the defense of a nation.

THE TRENDS AFFECTING VOCATIONAL EDUCATION

We cannot rest on the accomplishments of the past generation, in view of the conditions that will confront us during the next generation. Neither can we rest on the magnificent work of the present in the training of a labor supply for wartime industries. The accomplishments with respect to the broadening of the vocational program throughout America during this past generation are evident. We must secure a balance in our educational program that does not now prevail.

We are confronted with the need for continuous planning and action. There are evidences on the horizon toward which we must turn if we are to be guided in the proper direction. Some of the factors which will affect vocational education in the future are: declining school enrollment, the breakdown of the skilled trades into a series of jobs, the rapidly expanding apprenticeship program, the mass production of operators, the training-within-industry program of the War Production Board.

School Enrollment Declines. The statistical data on school enrollment have a distinct bearing on the future of vocational education. Frequently the objective of educational institutions may not be directed toward the welfare of the individual so much as toward protecting an enrollment. A qualitative criterion as the basis for operation has not been adopted generally. The facts revealed by the most recent available school enrollments are indicative of some of the problems. The following data illustrate the importance of the trend:

1. The total enrollment in United States public schools in 1928

was 25,179,696. The peak enrollment in 1934 was 26,434,193 pupils. A consistent decline has prevailed during the last eight years.

2. The elementary-school enrollment in 1928 was 21,268,417. This declined in ten years to 19,748,174, or 7 per cent.

3. High-school enrollment in 1928 was 3,911,275. It increased consistently to 6,226,934 in 1938, the peak year.

4. The enrollment in the first grade reached its peak with 4,171,037 in 1928. There was a consistent decline in the next ten years. Almost 900,000 boys and girls who should have been in the first grade if the trend of 1928 had continued are not there.

5. In 1918, 285,047 high-school and 27,915 college students graduated from their respective courses. Twenty years later there were 1,120,079 high-school graduates and 164,943 college graduates.

6. In 1870, there were only 16,000 graduates from high school out of 8,015,000 youth 17 years of age and over. In 1938, almost 46 out of every 100 youth 17 years of age graduated from high school. Of 2,458,000 of that age, 1,120,079 graduated.

7. There were in this country in 1938 21,049,000 boys and girls 5 to 13 years of age. By 1943, this group of 21,000,000 boys and girls will be 10 to 18 years of age. These are the youth who ultimately will determine the policies of this country.

The importance of these factors in the development of an educational program cannot be ignored. It is important therefore that as we reappraise and evaluate American education, a balance in our program be secured. There should be available to every boy and girl an opportunity to ascertain his or her fitness for occupations, to learn about the industrial and business resources of the country, to learn how to use his or her hands and talents to the maximum. These are needed as a balance to our highly academic procedure.

Breaking Down of Skilled Trades in the Job. The breaking down of the skilled trade into a series of jobs is no longer a matter of speculation. Because of the present crisis and America's past reluctance to train skilled workers, the desire on the part of many of our people to get out of anything that appears to be work, our failure to dignify work, and for a variety of other reasons, vocational education has not been as respectable as completing a college-preparatory course, so called. It was evident early, through the former Office of Production Management, that where skilled employees were not obtainable the engineer was called upon to reduce a given enterprise to a series of jobs in order to facilitate production. Thus much of the skilled work has been broken down into a series of operations suitably performed by semiskilled and in many cases by unskilled operators. There are many implications here both for labor and management as well as for training institutions. It is a trend that definitely cannot be ignored by educators. A long-delayed apprenticeship program now is under way. This is a basic essential in a complete educational opportunity. We have been without vision in delaying the growth of an apprenticeship program. This opportunity should provide for close integration with vocational schools or vocational opportunities within industry.

Job Training Does Not Produce Skilled Workers. There need be little comment on the purpose of the current training course for operators. It is designed to produce a labor supply rapidly. It is an induction into industry. It obviously does not produce skilled craftsmen. Too many youth, however, are under the impression that they are trained machinists as a result of having completed the work. This fact, together with exceedingly high wages for many youth who previously had earned little or had been on relief during the depression period, is producing a state of mind and an outlook with which there must be the utmost concern. Adjustments following the wartime effort will be extensive and severe.

SOME FUNDAMENTAL NEEDS

The transition in the secondary-school program will not be accomplished immediately. It is highly desirable that as changes are made full consideration be given to many important issues. The ability of all to think constructively and critically, rather than to accept without thinking the pronouncements of those with special interests, is fundamental in a democracy.

The very security of democracy itself is contingent upon the practical ability of the people to devise ways and means whereby all who desire to work may be provided with that opportunity. Men who own property and who have jobs are not the easy victims of subversive movements or of panaceas for their deliverance from a life of fear, want, unhappiness, joblessness, and lack of opportunity. Certain fundamental needs must be faced realistically. Only a few illustrations will be presented:

Work Should Be a Part of Education. Obviously, few people are interested in returning to the black page of yesterday when children labored long and hard. However, in our zeal to protect youth from the maturing value of work, we practically have made work itself a hazard. Certainly, the labor market should not be overcrowded by immature youth and adolescents. But the opportunity for every boy and girl, as part of education, to learn what hard work means—and that means manual labor, work with one's hands—must be reintroduced into our system. Work should be regarded as part of the educational program just as is Latin, mathematics, social science, or any other experience provided for the individual. In my judgment, with proper follow-up and supervision and recommendations from employers, it should receive credit on the high-school record and be accepted for college admission.

New Types of Colleges. It is obvious that the high-school program has been unduly academic in nature, though youth possess interest in other areas. Our colleges should provide admission based on the intellectual and social maturity of the individual and his capacity to read, write, and speak English. The procedure thus far is to gauge the student's competency or his desirability for college on his rank in the high-school graduating class and his capacity to pass certain specified courses.

Perhaps a difference in this respect should be made between the institution that specializes in the production of scholars and the institution of higher education that is dealing with average people. Those who have been the early and easy victims of subversive movements have been not only those without jobs and security, but many with insufficient schooling to enable them to distinguish between the forfeiture of their liberty and the panacea proposed for their deliverance. Too many young people fail in college; too many youth do not get to college because of economic inability of their parents. I believe then, that a system of scholarships should be made available to youth who because of economic incapacity ordinarily would be denied a college education.

The Search for Talent. I hope sometime in the United States we shall give scholarships or otherwise recognize the need for the development of ingenuity. Those who possess talent in any particular direction should be permitted to develop this talent to the utmost. I would hope, therefore, for the recognition of a system of education that would help perpetuate the ingenuity that has made our country famous. This means substantially that children should be permitted to develop to their greatest potentiality irrespective of race, nationality, economic condition, political affiliation, or any of the irrelevant factors that sometimes determine the future of the individual. Approximately as many competent youth are denied admission to college because of economic disability as enter because of parental ability to supply the financial means.

Determination of Fundamentals. Our secondary-school program generally represents a wide offering. Those subjects in the curriculum that are no longer of any particular use to large numbers of individuals should be eliminated. Fundamental changes ultimately may reduce the need for different subjects. This is particularly true if areas of experience supplant the narrow, subject-matter compartments. English, for example, should be taught as part of every course in the child's experience. The need for the specialist in speech, in reading, in the field of appreciation of literature is evident; so is the need for knowledge of arithmetic in high school.

Development of Marketable Skills and Aptitudes. The secondary school *may* develop in boys and girls marketable skills which will make employment much easier to secure upon completion of the 12th grade, or at such time as the individual may drop out of school. The further development of the program of arts and industries, beyond the present manual training or avocational approach; provision for review courses in arithmetic before leaving school; the concerted action of all teachers on such fundamentals as accuracy, neatness, thoroughness, ability to assume responsibility, willingness to follow directions, and many other qualities essential to employment—all these may be made possible in the comprehensive secondary school.

The Socially Competent Individual. It must be realized, too, that in the development of social competency the educational system as an institution or in co-operation with other institutions must provide sufficient opportunity for well-rounded development in several areas of life experience. Among the other areas are: (*a*) home and family life; (*b*) the socio-economic forces; (*c*) health; (*d*) ability to enjoy the aesthetic elements of life; (*e*) spiritual development of the individual; (*f*) natural environment; (*g*) training for work of the world with adequate provision for retraining opportunities.

These are trying times. It is altogether probable that many of the difficulties encountered during the period of the first World War may be repeated unless those in places of leadership are willing to face the situation realistically and without emotion. Plans must be well formulated. It is equally essential that there be recorded the almost universal desire on the part of our people for a better vocational opportunity for our youth. During ten years of a depression period, when many educators urged more vocational education and preparation for the days to come, few were willing to spend the additional sums to train the workers that ultimately were to be needed.

It seems to me that America should no longer hang its head or develop an inferiority complex. Our doctors no longer come from Vienna, our artists from Italy, our scholars from German or English universities. What have we to fear? It is in this country that the greatest inventive genius has developed. It is in this country that outstanding men of the medical profession, scientists, magnificent laboratories, tremendous research resources, and ingenuity unsurpassed anywhere in the world have evolved. We produce artists, musicians, skilled mechanics, as well trained as any in the world. We must provide greater opportunity for the discovery of talent. We must develop in our country an attitude toward work that will make graduation or completion of a vocational course of equal importance with graduation from an academic or college-preparatory course.

Men and women become citizens of the United States, and in that capacity determine the policies of democracy. Democracy is not safe until the people have been prepared to participate intelligently and rationally in the conduct of their own affairs. A constructive attitude toward government cannot be produced merely by waiting for it to develop. Let us remember this—each one of us is a citizen, whether he be a college graduate or possess merely a sixth-grade training. No one asks how much education a citizen has or what his intelligence quotient is when he casts his vote, runs for office, serves on a jury, or buys goods. The security of this country is vested in a trained citizenship. The first line of defense for the country is a citizenship prepared to do the work of the world; one that knows and is prepared to defend the things for which this country stands.

INSTITUTE ACTIVITIES

Vancouver Section Is Host to Its Fourth Pacific Coast Convention

The 27th AIEE Pacific Coast convention was held September 9–11 at the Hotel Vancouver in Vancouver, British Columbia. This was the fourth such meeting (1913, 1922, 1932, 1942) to be sponsored by the Vancouver Section since the program of approximately annual Pacific Coast conventions was initiated in 1910 under the sponsorship of the San Francisco Section. The recent meeting in Vancouver was the last national convention, as such, scheduled to be held by the Institute for the duration of the current war emergency, as the District and National technical meetings now being scheduled for future months will be devoted primarily to the discussion and interchange of information concerning technical developments and applications of especial significance in the war effort.

The several special features of the Vancouver program are reflected in the following report.

WAR NEEDS STRESSED

"Wartime National Efficiency" was the topic of a stimulating address given before a general dinner meeting on September 9, 1942, by G. A. Gaherty, president of the Montreal Engineering Company, Ltd., of Montreal, Que. Mr. Gaherty, briefly recounting significant aspects of the war, warned that:

"With all due respect for the splendid progress to date in the development of war materials and man-power resources, this is no time for complacency. We are facing a crafty and unscrupulous enemy. He has already cut us off from our main sources of three vital war materials—tin, tungsten, and rubber. He is taking a heavy toll of our shipping, and has played havoc with our lines of communication, notably his severing of the Mediterranean route to Suez. Our resources are being dissipated by convoying and by shipping via roundabout routes, by building ships to replace those he is sinking, and by constructing synthetic rubber plants. His resources, on the other hand, are increasing as he puts to work the enslaved peoples of Europe.

"Make no mistake of it, victory can be achieved only by the complete mobilization of all resources, and their skillful employment in *offensive* operations, in other words, total war . . . . The great weakness of democracies is that their resources too often are frittered away through the deciding of war policies upon grounds of political expediency instead of military strategy. . . ."

Mr. Gaherty's address is scheduled for early publication in *Electrical Engineering*.

Analysis of Registration at 1942 Pacific Coast Convention

Classification	District 10	District 9	District 8	Miscellaneous	Totals
Members	72	32	13	5	122
Men guests	32	7	4	1	44
Women guests	30	24	7		61
Enrolled Students	3	4	11		18
Totals	137	67	35	6	245

INTERNATIONAL PREJUDICES DISCUSSED

Speaking on the topic, "International Prejudices," W. J. Gilson, General Manager of Eastern Power Devices, Ltd., of Toronto, Ont., presented much food for thought concerning the great need for international understanding and the simple and controllable circumstances that so frequently lead to international prejudices and misunderstandings. Experiences cited from his own far-flung career served admirably to give point to his general thesis that stable international relationship can grow only out of the intelligence and the conscious thought and effort of the individual.

Mr. Gilson spoke before a joint luncheon meeting sponsored by the Vancouver Electric Club. The substance of his address is given on pages 525–6 of this issue.

EXECUTIVE MEETING

A joint executive luncheon meeting was held September 9, 1942, by the Section and District officers of the Pacific area, with Vice-President C. A. Price of the Canadian District presiding. National Secretary Henline reported the recent action of the board of directors (EE, September 1942, page 477) whereby national and District meetings will be continued—but stripped of all social activities and with heavier technical programs—as a technical contribution to the war effort. The Institute's technical work and its facilities for the effective exchange of useful technical information, of recognized value and importance in peacetime, are potentially much more vital in wartime, and it is intended that every Section and every technical committee shall devote its efforts primarily to war problems. Sections are especially asked by President Osborne to devote at least one meeting to the conservation of critical materials. Sections also were asked at the summer convention to bend every effort toward facilitating and effectuating local scrap and salvage programs. Other matters of local interest were discussed.

Next year's Pacific Coast technical meeting is scheduled to be held in Salt Lake City under the auspices of the Utah Section.

TECHNICAL PROGRAM

As far as subject matter is concerned, electrical apparatus—ranging from relays to metallurgical furnaces—accounted for 7 of the total of 19 topics presented at 5 technical sessions. Wartime problems in power-system planning and operation were covered in six papers, and extensively discussed. Three papers dealt with industrial and operating experiences, principally in electrometallurgy, and three were concerned with circuits and electrical theory. The most active discussion concerned the operating and industrial topics.

Power-system interconnection for the interchange of power is nothing new in the electric-power industry. The Vancouver discussions, however, revealed great extension and refinement of methods of coordinated intersystem operation directed toward the wartime objective of getting the maximum total kilowatt-hour output from groups of power systems. As an example of the effectiveness of such efforts, effective firm-power generating-plant capacity in excess of 100,000 kw was reported salvaged among a group of systems, each of which operating alone was loaded to maximum firm-power capacity.

Discussion revealed that war-stimulation of electrometallurgical industries in the United States has brought the installed capacity of rectifiers serving these industries to a total of nearly 4,000,000 kw, with some 600,000 kw in additional capacity currently being added in the Pacific Northwest alone. For this service the steel-tank rectifier heavily predominates, especially in the United States, although the glass-bulb rectifier has strong support and is the feature of several large installations, especially in Canada.

STUDENT PROGRAM

Continuing a long-established custom with respect to Pacific Coast conventions, a part of the program was given over to the following group of technical papers prepared by members of various Student Branches in that area:

THE DESIGN AND CONSTRUCTION OF A 25-WATT HIGH-FIDELITY PUBLIC-ADDRESS SYSTEM, R. E. Dye, R. C. Fortin; University of Idaho Branch, Moscow, Idaho.

LIGHTNING AND BROADCAST TRANSMITTERS, H. T. Stevinson; University of Alberta Branch, Edmonton.

FREQUENCY RESPONSE OF RECORDING HEADS DETERMINED BY LIGHT-PATTERN MEASUREMENTS, John Collins; University of British Columbia Branch, Vancouver.

A STUDY OF THE EFFECT OF HIGH-FREQUENCY FIELDS ON MICROORGANISMS, Hugh Fleming; Oregon State College Branch, Corvallis.

NEEDLE-GAP-SPARKING VOLTAGE VARIATION AT LOW AIR PRESSURE, **W. J. McBride, R. H. Foy;** University of California Branch, Berkeley.

HEAT-FLOW STUDY BY ELECTRICAL ANALOGY, **Roger Brandt;** California Institute of Technology Branch, Pasadena.

LOW VOLTAGE BLACK-OUT ALARM AND SIGNAL SYSTEM, **A. H. Elliott;** University of British Columbia Branch, Vancouver.

ANALYSIS OF DISSIMILAR DELTA TRANSFORMER BANKS, **Glen E. Bredemeier;** Oregon State College Branch, Corvallis.

As the result of current conditions and the fact that many colleges were in essentially full operation, the total student attendance was somewhat lower than usual. Even so, there were present Student Branch chairmen or others representing 12 of the 15 Branches in the area, and counselors or other faculty representatives from 12.

Group meetings of the representatives present resulted in the selection of District officers as follows:

District 8, *chairman of student activities*—Professor F. W. Maxstadt, California Institute of Technology, Pasadena.

District 9, *chairman of student activities*—Professor R. E. Lindblom, University of Washington, Seattle.

At a luncheon conference of Student Branch representatives, counselors, and others interested, there were several brief addresses concerning various Institute activities and a general exchange of ideas concerning effective Branch activities. This conference was presided over by Vice-President E. W. Schilling of Bozeman, Montana. All 15 of the Student Branches in the Pacific area were represented by either the Counselor or the student chairman—9 by both. National Secretary H. H. Henline gave a brief outline of the present status and objectives of the Institute and its position with respect to other professional organizations. He called special attention to the action recently taken by the board of directors, directing the Institute's technical meetings and other activities primarily toward war problems. He mentioned also that 1942 is the fortieth anniversary of the initial steps to provide for Student Branches in the Institute's organizational structure. Editor G. R. Henninger explained the essential features of the Institute's present publication policy and procedure, whereby most technical papers and much other material of current importance reach each member promptly through the monthly issues of *Electrical Engineering*. Vice-President W. C. Smith of San Francisco spoke briefly on behalf of District 8, as likewise did Professor J. C. Clark of the University of Arizona, Tucson, who presented a summary of the Student Branch matters as discussed at the recent Summer convention in Chicago.

Pacific Coast Convention Registration—1932–1942

Year	Location	Registration
1942	Vancouver, B. C.	245
1941	Yellowstone Park	322
1940	Los Angeles, Calif.	465
1939	San Francisco, Calif.	*
1938	Portland, Ore.	454
1937	Spokane, Wash.	266
1936	Pasadena, Calif.	*
1935	Seattle, Wash.	269
1934	Salt Lake City, Utah	232
1933	(No Pacific Coast convention)	
1932	Vancouver, B. C.	300

* Combined with summer convention.

ENTERTAINMENT AND SPORTS

Principal feature of the war-limited social program was the 22d annual competition for the John B. Fisken cup. This year's winner was Bernard De M. Mertens (A'14, M'25) of the British Columbia Electric Railway Company, Ltd., Vancouver (Vancouver Section), whose low net score of 71 was achieved by a gross total of 85 and handicap of 14. Runner-up was J. C. Henkle (M'36) of the Portland (Oreg.) General Electric Company (Portland Section) (82−8=74 net). The low gross score of 80 was made by J. W. Butler (A'31, M'38) of the General Electric Company, Schenectady, N. Y. (Schenectady Section). E. G. Cuilwick (A'26, M'33) of the University of Alberta (Edmonton Section), Edmonton, was runner-up, with a score of 83.

The Fisken trophy is a Pacific Coast institution, only active members of the Los Angeles, San Francisco, Salt Lake City, Spokane, Portland, Seattle, and Vancouver Sections being eligible for competition. Custody of the cup for one year, and the engraving of the winner's name on the cup is the coveted privilege of winner of low-net score. John B. Fisken himself presented the trophy to Mr. Mertens at a joint luncheon sponsored by the Vancouver Electric Club.

Other social features included a luncheon party, musical program, and a bridge-tea for women guests, and a formal dance for all those attending the meeting.

"International Prejudices" Discussed at Vancouver

Great oaks of international misunderstanding grow from little acorns of individual—and usually ill-founded—prejudice. Such in essence was the theme of a thought-provoking address given at the Pacific Coast convention, September 9–11, 1942, in Vancouver, B. C., by W. J. Gilson (A'26, M'38), general manager of Eastern Power Devices, Ltd., of Toronto, Ont. The occasion was a joint luncheon sponsored by the Vancouver Electric Club. The essential substance of Mr. Gilson's address follows.

EMOTION VERSUS INFORMATION

I recently commenced reading a rather lengthy book entitled "War and Peace" by the famous Russian author Leo Tolstoy. In the preface inserted by the publisher, the reviewer, Clifton Fadiman, states that Tolstoy intently studied individuals in a small group, and then integrated their behavior into group behavior in order to try to analyze the laws of history. Now, this is not a new thought by any means. In electrical engineering we use precisely the same method of diagnosing performance on a large system, by studying the behavior of a small circuit of known dimensions.

I wish to stress this method of logical appraisal. Study your own hearts and appetites and desires, and then study the group of people with whom you come into daily contact. Then try to integrate this group into one common channel of well-defined approach towards the truly democratic and Christian way of life about which we hear so much. I think if you are observant, reasonably dispassionate, and honest, you will be forced to make the channel a very broad one to take care of the harmonics. (But a common channel can be found if one is ready and willing to accept the law of averages.) This is the keynote to the existence of prejudice, both local and civic, religious and political, national and international.

Most of us are not willing to consider our own deficiencies when contemplating those of others. We become irritated when people of other religious, political, or racial groups express views which appear at variance with our own. We talk freely about democracy and Christianity, but we do not significantly appraise or try to control the steady betrayal of these principles by a certain percentage of people in each group and community. Ignorance, fear, and emotionalism, which form the prime ingredients for predjudice, unfortunately are not confined to the uneducated or poorly educated people. They stalk through every branch of human society from the bottom to the top, and are virtually unchecked except by the almost imperceptible upward movement in the progress of human intelligence through the ages.

Dare I mention the wave of bitterness and prejudice which was so abundantly in evidence in a certain large republic on the American continent during a presidential election in 1940? Sharp intolerance and rampant prejudice were running wild on a wave of pure emotionalism. Some people emerge from such a delirium as they would from the aftermath of a college football final, but many allow their intolerance to harden and their sense of proportion is then permanently out of order. These are the people who create the Hitlers and Mussolinis.

My interest in the international viewpoint started as a boy of fourteen and was not altogether a voluntary procedure. I received my early education in a little country school in northern California, and in due course learned all about the Revolu-

tionary War. At age 14 I was sent to school in England, and I found that the English boys had an entirely different conception of the Revolutionary War, and were just as sure of their ground as I was. They also gave me some supplementary data about which I knew nothing, and which placed me somewhat at a disadvantage. I learned of the British preoccupation with the French during this period, and also that the British Parliament was sharply divided in its support of the attempt to suppress the American Revolution. The records of speeches made by the Opposition leader, William Pitt, to the House of Parliament on this subject stand as undeniable testimony of free speech and liberal thinking in England, even in those days.

To the American schoolboy the Revolutionary War was a number one man-sized affair crowned by victory. To the British schoolboy, that colonial affair was an unfortunate family squabble which was handled very indifferently because of other more pressing events closer to home.

CONSIDER AVERAGES, NOT INDIVIDUALS

I was aggressively certain at that time that any full-grown American could lick five wild cats bare-handed. The English boys seemed very unimpressed. Maybe they weren't so sure about the five wild cats, but they were quite certain that any Englishman was immeasurably superior to any other adult species of homo sapiens not indigenous to the sovereign domain of England. I fought many a bitter scrap to prove my point, and with a fair degree of physical success, but it gradually dawned upon me that bloody noses and bruises didn't seem to have any influence on the psychological problem. I also found out over a period of time that some of these English boys were ace-high and presumably their fathers were before them, and so I received my first lesson about the law of averages.

Later on, World War I broke out, and in 1915 at the age of 17 I joined the British Army. During this war period, with troops of different nations constantly intermingling—English, French, Irish, Scottish, Canadian, Australian, American, Portuguese, and Belgian—I was keenly interested in noting that there was a small percentage in each group with which I came into contact who appeared to be roused easily to antagonism against one, or more, or perhaps all other national groups. They were only a small percentage, but they very often influenced their fellow nationals to quite a degree. While I appreciate how dangerous it is to generalize, in summing up my experiences and observations in later years I decided that most of the individuals in these groups, regardless of nationality, had characteristics very much in common. For the most part they were what I now term 100-per-centers. They were 100 per cent English, or 100 per cent American, or 100 per cent French, and they are still with us. These 100-per-centers have never heard of the law of averages, they have no conception of tolerance. You either belong to their group and talk their language, or you just don't rate. Further than that, if you dare to suggest that it is slightly illogical to cleave the whole world into one small group, all white, and to consider all the rest black, you are in for either cold disdain or a white-hot tongue lashing.

BEWARE THE 100-PER-CENTER

It is of course true that these 100-per-centers perform a great deal of valuable work during war periods because their high pitch of emotional behaviorism is very closely associated with that all-important spirit called morale. Nevertheless they are also at the root of most of our international pitfalls and prejudices. Hitler undoubtedly is a 100-per-center and so are all his cohorts.

All national groups have different viewpoints on many things, and also at least slightly different standards of values, both moral and physical. Somewhere through the middle runs an average to which we all probably could subscribe without much national loss or gain. But it is usually on these small differences that misunderstandings arise and grossly unfair, sweeping judgments are made.

For example, there is a fundamental difference in the attitude of the British and that of the people of the North American continent toward sports. This also was part of my early education in learning to appraise people on the basis of the law of averages.

In England, football, cricket, badminton, and even boxing are faintly reminiscent of the "ye goode olde days" we read about when knights in shining armor went forth to show that they could "take it" and be jolly good sports even with a cracked pate. The English crowd likes the finesse of the game and an occasional sample of giving the other fellow a break. They can be more enthusiastic over a good loser than a winner who appears to disregard their finely drawn sporting code. Here in the United States, in football, baseball, hockey, boxing, and other sports, the whole technique is the essentially simple one of playing to win. There is no reason why people in either country should feel that their viewpoint is right and the other viewpoint wrong. Both are reflections of perfectly accidental habits which have followed different patterns.

For a short time in 1921 I worked at a sugar refinery in Crockett, California. One of my work mates there, who hailed from San Francisco, had served as a top sergeant with one of the United States regiments in France. He was a typical 100-per-center. The United States had won the war—the French were so-and-so's who played the United States for suckers—and the British—nothing was too bad to say about the British. Yes sir, he had been in England and sized them up for himself. I got him alone one day deliberately to ply him with a few questions, and this is what I learned. He told me that his father had been born in England, and that he had always thought England and the English were O.K., until he went there. He had spent a ten-day furlough in England just before returning to the United States after the Armistice. The ten days were spent in cheap hotels in London and Liverpool. He had seen nothing at all of the charming English rural towns. He had met no decent English families, but had been in a riotous free-for-all in one of the Liverpool pubs or beer parlors, and later on had his wallet stolen. That was the sum of his contact with England and the English, and on such flimsy, fleeting, misguided experiences he summarily condemned a nation. On such comparatively minor differences and misunderstandings are international prejudices and enmities created.

Returning to this question of individual intolerance integrated into group behavior, I wish to stress again the damage done to broad understanding and intergroup or international harmony by these people I term 100-per-centers. To be 100-per-cent behind any temporary action such as the present war (which we hope *is* temporary) or a sports movement, or even an AIEE convention is necessary for practical purposes and is logically sound. However, to be 100-per-cent behind any group movement which tends to set up exclusive standards for one chosen clique or race is obviously wrong, and downright insulting to those in other groups. In a sociological sense one cannot be 100-per-cent anything unless one is 100-per-cent for humanity as a whole. If this is not true, then the fundamental basis of our Christian way of life reeks with hypocrisy and is absolutely rotten to the core.

EMOTION VERSUS LOGIC

In order to avoid any misunderstanding, let me state a belief that it is not necessary, in fact it is downright dangerous, to work up emotional peaks on alleged racial superiority even during a war period. There was nothing emotional about any first-class boxer I ever met, at least not with respect to his job of scientifically beating up some opponent. In fact, in boxing one is trained deliberately to develop the detached viewpoint because emotional disturbances not only cause faulty judgment, but also burn up too much reserve energy. The fact that a good boxer does not hate his opponent or think he's an inferior beast does not hinder the boxer from doing a first-class job of pounding the daylights out of his opponent, if he is able to do so.

In this war, we have a job of severe corporal punishment to mete out against those foreign 100-per-centers who have led their groups and races by the nose through their fanaticism. This short-term trend, however, does not relieve any of us from our share in the common problems of world humanity when we finish smashing the gangster gangs.

"Calculation of Fault Currents" Available in Reprint Form

The report, "Simplified Calculation of Fault Currents," prepared by the AIEE committee on protective devices, which appears on pages 509–11of this issue, is being made available in reprint form. The sub-

ject is of widespread interest and it is believed that Institute members and others may wish to have reprint copies for convenient reference. The report may be obtained from AIEE headquarters, 33 West 39th Street, New York, N. Y., at 15 cents per copy with a 20 per cent discount allowed on ten or more copies sent to the same address at the same time. Quantity prices will be quoted on application.

"Conservation Through Good Engineering" Is Technical Program Theme

"Conservation Through Good Engineering" is the wartime theme adopted as a basis for AIEE technical programs in the immediate future. This action was taken by the AIEE technical program committee at its meeting held September 18, 1942, at national headquarters in New York City, in accordance with the new AIEE Wartime Policies as defined and reported on page 477 of the recent September issue of *Electrical Engineering*.

Under this program each technical committee, so far as possible, will review its existing standards and methods of application of electrical apparatus, recommendations of the National Electrical Manufacturers Association and the War Production Board for the closer selection or maximum safe loading of apparatus; and will prepare "guides" or "general principles" similar to the transformer subcommittee report (42-156), published beginning page 692 of the *Transactions* section of the September 1942 issue of *Electrical Engineering*.

ADHERE TO BASIC STANDARDS

These guides will serve a double purpose. First, they will educate users to apply equipment more closely and to lay out systems in such a way as to conserve copper and other strategically important materials. Secondly, they will serve to educate users in the more diverse application of standard apparatus, through showing how apparatus will perform under widely varying conditions, and what the maximum limits of safe application are. It is believed that the existing AIEE and American Standards are fundamentally sound, so that the war objective will be far better served by educating users to apply standard equipment more closely, than by any possible revisions of the Standards themselves.

The technical program committee believes that through the preparation of these committee reports the Institute can perform a very useful service in the war effort. While the list of topics to be covered is not final, the accompanying tabulation of nine subjects definitely has been undertaken by the committees indicated.

REPORTS TO BE AVAILABLE FOR LOCAL DISCUSSION

As rapidly as they are completed, these reports will be available for discussion at Section meetings and at national, and District technical meetings. It is hoped that in many cases Section meetings may be arranged jointly with other engineering groups, or in co-operation with the War Production Board, so that the recommendations in these committee reports may be put to the best possible local use.

With reference to the national program to reduce waste through fires, as reported on page 493 of the September issue, Institute technical committees plan to give particular attention in the preparation of these reports and elsewhere to methods and practices that will reduce the risk of electrical fires.

Proposed AIEE "Guides (or Principles) for the Selection and Operation of Electric Equipment"

To Be Prepared by Technical Committees, not Later Than January 1, 1943, if Possible

Topic	Sponsoring Committee and Chairman
Report Already Published	
Interim Report on Guides for Overloading Transformers and Voltage Regulators; AIEE Paper 42-156; 15 cents by mail	Transformer subcommittee, committee on electrical machinery, M. S. Oldacre, chairman
Reports Under Preparation	
Distribution transformers and voltage regulators	Transformer subcommittee, committee on electrical machinery, M. S. Oldacre, chairman
Switchgear	Committee on protective devices, T. G. LeClair, chairman
Current capacities of bare conductors	Committee on power transmission and distribution, Philip Sporn, chairman
Low-voltage insulated cables	Committee on power transmission and distribution, Philip Sporn, chairman
Supply of rkva (or kilovars) on distribution systems	Committee on power transmission and distribution, Philip Sporn, chairman
Industrial power-distribution systems	Committee on industrial power applications, J. J. Orr, chairman
General purpose motors and controls	Committee on electrical machinery, F. E. Harrell, chairman
Power-generating equipment	Committee on power generation, A. C. Monteith, chairman

Future AIEE Meetings

National Technical Meeting
New York, N. Y., January 25–29, 1943

District Technical Meeting
Providence, R. I., April 7–9, 1943

District Technical Meeting
Kansas City, Mo., April 28–30, 1943

National Technical Meeting
Cleveland, Ohio, June 21–25, 1943

STANDARDS • • •

The following AIEE standards may be obtained from AIEE headquarters, 33 West 39th Street, New York, N. Y., at the prices specified. A 50 per cent discount is allowed to AIEE members on single copies.

Apparatus Bushings. This standard (No. 21) which includes as an appendix the "Test Code for Apparatus Bushings" was approved by the board of directors on June 24, 1942. It has been available in report form since March 1941. The standards specifically cover the following types of bushings: (a) outdoor bushings for large apparatus; (b) cover-type bushings for small apparatus; (c) indoor bushings for all types of apparatus except dry-type instrument transformers, air-blast transformers, dry-type regulators, circuit breakers rated below 5,000 volts, and nonoil-tight oil circuit breakers rated 50,000 kva or less. These standards are not intended to apply to wall bushings, cable potheads, or insulators for back-connected disconnecting switches, although many of the principles may be applicable. The bushing requirements as specified in these standards apply to bushings when mounted for testing in accordance with specified arrangements as given in the Test Code—Appendix I. (40 cents.)

Air Switches and Bus Supports. This revised standard (No. 22) approved by the board of directors June 24, 1942, supersedes the former standard of the same title which was approved for a trial period of approximately one year. The standard covers all types of air switches and bus supports above 600 volts whether for indoor or outdoor service. It does not apply to air circuit breakers covered by standard No. 20. (40 cents.)

Switchgear Assemblies. This revised standard (No. 27) approved by the board of directors August 7, 1942, supersedes the former "Standard for Switchboard and Switching Equipment for Power and Light" (No. 27) of October 1930, and its proposed revision "Switchgear Assemblies" (No. 27A) of March 1941. These standards cover assemblies of switchgear devices such as switches, interrupting devices, control, metering, protective and regulating equip-

ment with associated interconnections and supporting structures. These standards do not apply to industrial control equipment, communication switchboards, switching equipment, or switchboards for shipboard. (30 cents.)

Guiding Principles for the Selection of Reference Values for Electrical Standards. This pamphlet (No. 3), a proposed standard approved for a trial period of approximately one year, is designed to serve as a guide in the preparation or revision of standards for apparatus or materials of specific types or fields of use. If a particular existing standard calls for other provisions, the existing standard should be followed. The values given are not mandatory, but are recommended for use in preference to other values unless there are good technical or economic reasons for using others. The values recommended have in general been selected to agree with well established practices. Provisions are made for a great variety of conditions and for widely different apparatus and materials, some of which may be of practical importance only under unusual circumstances. (No charge.)

Neutral Grounding Devices. This pamphlet (No. 32) is a proposed standard approved for trial use, which applies to grounding transformers, and to resistors, reactors, capacitors, and combinations of these, when used for grounding the neutrals of a-c electric systems. (No charge.)

PERSONAL ....

G. Ross Henninger

D. C. Prince

C. R. Beardsley

G. Ross Henninger (A'22, M'27), AIEE editor since 1933, has been granted leave of absence to accept a commission as lieutenant colonel in the Army Specialist Corps. He will serve as liaison officer on the headquarters staff of the Corps at Washington, D. C. He was born in Hamilton, Ohio, May 22, 1898; attended the public schools of Ocean Park, Venice, and Santa Monica, Calif.; received the degree of bachelor of science in electrical engineering from the University of Southern California, Los Angeles, with the class of 1922, after completion of extracurricular work in the fields of civil engineering and business administration. During his university career he was a full-time employee of the Southern California Edison Company, Ltd., serving in the company's operating department as a substation and powerhouse night-shift operator. Upon graduation, he entered the student course of the Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., subsequently becoming a member of the relay section of the company's supply engineering department where he spent a year in laboratory, office, and field work. Leaving the employ of the Westinghouse company, Mr. Henninger re-entered the services of the Edison Company in 1923 as operating assistant to the electrical protection engineer, in which position he was charged with responsibility for the satisfactory operation of protective relay equipment throughout the company's system. In 1924, he left the Edison company and moved to San Francisco to become engineering editor of the then *Journal of Electricity* (which subsequently changed its name to *Electrical West*) the Pacific Coast publication of the McGraw-Hill Publishing Company, Inc. In that position he developed and was in responsible charge of the technical department of the magazine until he went to New York in 1930 as associate editor for the AIEE. He remained in the latter position until he was named editor in 1933. In addition to his duties at AIEE headquarters, he devoted a substantial amount of his time from January to June 1942, to the United States Navy Department, in Washington, in the organization of an editorial and review section for the co-ordination of Navy technical material. Mr. Henninger had been active in Institute affairs for many years prior to his employment on headquarters staff. He was one of the organizers and was first chairman (1921) of the Student Branch at the University of Southern California; he served on various Pacific Coast convention committees (1925–30); served the San Francisco Section successively as member of the executive committee, secretary, and vice-chairman. During his employment by the Institute, he has served in various capacities in activities carried on jointly by AIEE and other societies, including: publicity committee, American Engineering Council (1937–40); information committee, Engineers Council for Professional Development since 1934 (chairman 1941–42). Mr. Henninger also has been active in civic affairs in his home community, having served as vice-president, Teaneck, N. J., Taxpayers League, 1934–36; trustee, Haworth, N. J., Municipal Library since 1936; member of the Haworth Board of Education since 1940 (currently president). He is also a member of the Society for the Promotion of Engineering Education.

D. C. Prince (A'16, F'26) vice-president in charge of application engineering, apparatus department, General Electric Company, Schenectady, N. Y., has been appointed chairman of the AIEE committee on planning and co-ordination for 1942–43. He was born February 5, 1891, at Springfield, Ill., and was graduated from the University of Illinois with the degrees of bachelor of science (1912) and master of science (1913) in electrical engineering. In 1913 he entered the test course of General Electric Company at Schenectady. From 1914 to 1917 he was employed on valuations and ratemaking by the Illinois State Public Utilities Commission, and from 1917 to 1919 he served in the United States Army. He returned to the General Electric Company in 1919 and the following year was appointed a research engineer in the radio department. In 1923 he was assigned to the research laboratory, first to work on vacuum-tube applications and later on power control. He was transferred to Philadelphia in 1929 as research engineer of the switchgear department, becoming chief engineer in 1931. He served in this capacity until 1940, when he became manager of commercial engineering for the General Electric Company in Schenectady. In 1941 came his appointment to his present position. Mr. Prince is a past president (1941–42) of the Institute. He was a member of the board of directors (1938–41) and the board of examiners (1938–40), and has been a member of the Charles A. Coffin Fellowship and Research Fund, the Charles LeGeyt Fortescue Fellowship, Lamme Medal, Edison Medal, and finance committees and the committees on transfers, protective devices, and air transportation. He has been AIEE representative on the John Fritz Medal Board of Awards since 1941, and at present is serving as AIEE representative on the Engineering Societies' 1942–43 joint committee on postwar planning. He is the author of many technical papers and articles, is co-author of two books, and holder of a number of patents. He was honored in 1939 as a "modern pioneer" by the National Association of Manufacturers. He also is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

C. R. Beardsley (A'08, F'30) has been appointed chairman of the AIEE special committee on registration of engineers for 1942–43. He is on wartime leave of absence from Consolidated Edison Com-

pany of New York (N. Y.), Inc. to act as assistant to the commissioner of the Department of Commerce of the City of New York, and is engaged in war-production problems in the Greater New York area. Mr. Beardsley was born December 19, 1885, in Bridgeport, Conn., and was graduated from Yale University in 1905 with the degree of bachelor of philosophy in electrical engineering. From 1905 to 1911 he served in various capacities with the General Electric Company, Schenectady, N. Y. and New Haven, Conn., and in 1911 became sales agent in charge of layouts and industrial distribution. In 1918 he joined Fred T. Ley and Company, Springfield, Mass., as electrical engineer in charge of design and installation of power stations. In 1923 he became electrical construction engineer with Brooklyn (N. Y.) Edison Company, and was successively appointed assistant to superintendent of distribution (1932) and superintendent of distribution (1934). He was transferred to the Consolidated Edison Company in 1938, was made manager of the contract control and inspection department in 1939, and associate manager of station construction and shops in 1942. Mr. Beardsley was a member of the AIEE board of directors (1937–41), and was chairman of the New York Section (1935–36). He was chairman of the special committee on model registration law (1937–39), until its functions were taken over by the committee on legislation affecting the engineering profession, of which he was chairman (1939–41). He also has been a member of the Edison Medal and technical program committees and the committee on institute policy. He is currently serving as AIEE representative on the National Bureau of Engineering Registration and as a member of the AIEE committee on code of principles of professional conduct. He is the author of many technical papers.

Robin Beach (A'15, F'35) professor and head of the electrical engineering department, Polytechnic Institute of Brooklyn (N. Y.), has been appointed chairman of the AIEE committee on education for 1942–43. He has served on that committee since 1935. He was born at Robin's Island, Long Island, N. Y., August 30, 1889, and received the degrees of bachelor of science in electrical engineering (1913) and electrical engineer (1922) from the University of New Hampshire, and master of science in physics (1922) from New York University. In 1913 he served as an instructor in engineering drawing and descriptive geometry at the University of Illinois, Urbana, and in 1914 became assistant professor of electrical engineering at Texas Agricultural and Mechanical College, College Station. In 1917 he was appointed head of the department of electrical engineering at Norwich University, Norwich, Vt., and the following year was appointed to the electrical engineering faculty of the Brooklyn Polytechnic Institute as associate professor. In 1927 he received his full professorship and in 1930 was appointed head of the department of electrical engineering. In addition, he also served as educational director for the Brooklyn (N. Y.) Edison Company from 1922 to 1933. Professor Beach has been a member of the AIEE committee on production and application of light since 1935 (chairman 1937–38), and previously served on the same committee during 1933–34. He has been AIEE representative on the United States national committee on the International Commission on Illumination since 1937, and is currently serving on the standards and technical program committees. He is a member of the Society for the Promotion of Engineering Education, and is also a member of Eta Kappa Nu and Tau Beta Pi.

T. F. Barton (A'12, F'30) commercial vice-president and district manager, General Electric Company, New York, N. Y., has been appointed chairman of the AIEE finance committee for 1942–43. He has been a member of the finance and executive committees since 1939, and also has served on the membership committee, the committee on transfers, and the board of examiners. He was chairman of the AIEE New York Section in 1932–33, a vice-president in 1939–40, and is serving currently as a director of the Institute. He was chairman of the committee on legislation affecting the engineering profession (1935–37), and has been also a member of the committees on the economic status of the engineer and industrial power applications. At present he is a member of the Edison Medal and headquarters committees, and the committee on planning and co-ordination. Mr. Barton was born December 25, 1887, at Rowesville, Orangeburg County, S. C., and received from Clemson College the degree of bachelor of science in electrical engineering in 1906. He entered the testing department of General Electric Company, Schenectady, N. Y., in 1906, and in 1909 was transferred to the d-c engineering department. He served in the engineering department of the New York office from 1911 to 1917, when he returned to Schenectady as a section head in the central-station engineering department. He became district engineer of the New York district in 1927, assistant manager of the New York district in 1939, and in 1940 was appointed to his present position. Mr. Barton has twice won Charles A. Coffin Foundation awards for contributions to the electrical industry.

J. R. North (A'21, F'41) assistant electrical engineer, Commonwealth and Southern Corporation, Jackson, Mich., has been appointed chairman of the AIEE standards committee for the year 1942–43. He has served on this committee since 1941. He was born in Cambridge, Mass., February 20, 1900, and received the degree of bachelor of science in electrical engineering at California Institute of Technology in 1923. He was a substation operator for the Southern California Edison Company, Los Angeles, Calif., 1920–23, and during 1922–23 was an assistant instructor in electrical engineering, California Institute of Technology, Pasadena. He was a student engineer with the Westinghouse Electric and Manufacturing Company at East Pittsburgh and Sharon, Pa., during 1923–24. Since 1924 he has been associated with Commonwealth and Southern Corporation and its predecessors, first as engineer in the investigation division, then as assistant investigation engineer (1927), and general technical engineer (1931). He has held his present position since 1939. Mr. North was chairman of the AIEE Michigan Section in 1934–35, and has been a member of the technical program committee and the committees on protective devices, electrical machinery, and the economic status of the engineer. He is serving at present on the Institute's committee on planning and co-ordination, and is AIEE representative on the electrical standards committee of the American Standards Association, and on the United States National Committee of the International Electrotechnical Commission. He is also a member of the Edison Electric Institute and Tau Beta Pi.

Robin Beach

T. F. Barton

J. R. North

H. A. Kidder (A'06, F'29) retired superintendent of motive power, the Interborough Rapid Transit division of the New York City (N. Y.) Transit System, has joined the Chemical Construction Company, New York, N. Y., as assistant to the general supervisor of plant operation. He is in charge of the operation of power plants. Mr. Kidder entered the student course of the General Electric Company, Schenectady, N. Y., in 1903, and spent

H. H. Race

E. T. Mahood

T. G. LeClair

S. B. Williams

three years in the testing department. In 1906 he was transferred for a brief period to the railway motor department, and subsequently became associated with the Interborough Rapid Transit Company as assistant electrical superintendent. He was successively appointed electrical superintendent (1914), assistant superintendent of motive power (1920), and superintendent of motive power (1921), a position he held until his retirement in June, 1942. He has served as chairman of the AIEE headquarters (1925–26) and finance (1926–28) committees, and chairman of the committees on co-ordination of institute activities (1928–30), the engineering profession (1929–31), and legislation affecting the engineering profession (1931–32). He was a member of the executive committee (1926–30) and the board of examiners (1930–40), and has served on various technical and special committees.

H. H. Race (A'24, F'39) research engineer, General Electric Company, Schenectady, N. Y., has been appointed chairman of the AIEE technical committee on basic sciences for 1942–43. He has served on that committee since 1933. He was born February 12, 1899, in Buffalo, N. Y., and was graduated with the degrees of electrical engineer (1922) and doctor of philosophy (1927) from Cornell University. He was a student instructor in electrical engineering laboratory at Cornell University (1920–22), and in 1922 he became a design engineer in the transmission and distribution department of the Philadelphia (Pa.) Electric Company. He returned to Cornell University in 1923 to serve as instructor in advanced technical theory, becoming assistant professor in 1927. He was placed in charge of courses in junior electrical theory in 1928. He joined the research laboratories of the General Electric Company, Schenectady, N. Y., in 1929 as a research engineer, directing projects on electrical properties of liquid and solid insulating materials. In 1928 he was awarded the National and North Eastern District prizes for an initial paper. He was chairman of the AIEE sections committee (1938–40), and has been a member of the research and publication committees, and the committee on planning and co-ordination. He is currently serving on the standards, technical program, and publication committees. He is the author of a number of technical articles and papers. Doctor Race is a member of the American Physical Society, American Association for the advancement of Science, and the National Research Council, as well as Eta Kappa Nu, Sigma Xi, and Tau Beta Pi.

E. T. Mahood (A'26, F'36) engineer, Southwestern Bell Telephone Company, Kansas City, Mo., has been appointed chairman of the AIEE sections committee for 1942–43. He has served on that committee since 1936. Mr. Mahood was born in St. Louis, Mo., August 3, 1887, and was employed by the Bell Telephone Company, St. Louis, Mo., in 1904 as a draftsman. He has been employed continuously in telephone plant and engineering work by this company and its successors since then. He was made district plant engineer in Wichita, Kans., in 1911, division plant engineer in Little Rock, Ark., in 1912, and plant engineer in Topeka, Kans., in 1917. He was transferred to St. Louis, Mo., as valuation engineer in 1919. In 1926 he became engineer in charge of the Western Missouri and Kansas area, Southwestern Bell Telephone Company. Mr. Mahood is a past chairman of the Kansas City Section (1935–36), and is serving now as AIEE vice-president representing District 7. He is serving also as a member of the committees on communication and on planning and co-ordination.

T. G. LeClair (A'24, F'40) supervising development engineer, Commonwealth Edison Company, Chicago, Ill., has been appointed chairman of the AIEE committee on protective devices for the year 1942–43. He has served on that committee since 1931. He was born at Superior, Wis., August 26, 1899, and was graduated from the University of Idaho in 1921 with the degree of bachelor of science in electrical engineering. In 1922 he was a student engineer with General Electric Company, Schenectady, N. Y., and entered the employ of Commonwealth Edison Company in 1923 as a cable engineer. He was transferred to the inside plant department as substation field engineer the following year, and in 1927 he became engineer of system protection. In 1930 he became a staff engineer in the office of the chief electrical engineer, in 1932 was made development engineer, and since 1936 has held his present position. Mr. LeClair has been a member of the AIEE board of directors since 1941, and has served on the membership committee, and the committees on land transportation, legislation affecting the engineering profession, and the Engineering Societies' joint committee on Chicago Century of Progress Exposition (1932–33). He is now serving on the 1942–43 Edison Medal, standards, and technical program committees. He holds patents on several inventions and is the author of various technical papers and articles. He is director and chairman of the legislating committee of the Illinois Engineering Council, and a member of the Western Society of Engineers and the Illinois Society of Engineers.

S. B. Williams (M'37) editor, *Electrical World*, New York, N. Y., has been appointed chairman of the AIEE Lamme Medal committee for the year 1942–43. He has served on the publication and Lamme Medal committees since 1939, and was appointed acting chairman to fill a vacancy on the latter in May 1942. He was born August 2, 1889, at Orinoke, Kans., and received the degrees of bachelor of literature (1912) and bachelor of electrical engineering (1914) from Princeton University. In 1914 he joined the staff of the *Electrical World*, McGraw-Hill Publishing Company, New York, N. Y., later becoming assistant managing editor. He became associated with the Gage Publishing Company, New York, N. Y., in 1922, as managing editor and later editor of the *Electrical Record*. He was manager and editor of *The Electragist* from 1924–28, when he returned to McGraw-Hill Publishing Company as editor of *Electrical Contracting*. He became managing editor of *Electrical World* in 1936 and has held his present office since 1938. He is a member of the Illuminating Engineering Society.

C. E. Hickey (A'20) former manager, distribution operation department, Consolidated Edison Company of New York (N. Y.) Inc., has been appointed manager

of the newly created outside plant construction department. He has been employed continuously by Consolidated Edison and allied companies since 1904. **J. E. Gallagher** (A'24, M'36) formerly general superintendent, station construction and shops, has been transferred as general superintendent to the department of electrical construction. He came to Consolidated Edison from the Brooklyn (N. Y.) Edison Company. **G. C. Baker** (A'20, M'25) engineer of estimates, contract control and inspection department, has been made superintendent of estimates and orders. **E. E. Hill** (A'16) formerly general superintendent, distribution construction bureau, has been transferred as manager of the distribution operation department. He first joined the company in 1904 as assistant meter tester, the New York (N. Y.) Edison Company. **W. T. Grumbly** (A'28, M'36) head of the outside plant inventory bureau, was appointed superintendent of the Manhattan and Bronx electrical division of meter department, and was later transferred as head of the test bureau of the electrical engineering department.

W. P. Graham (A'02, F'23) former chancellor of Syracuse University, Syracuse, N. Y., retired in June. Born in Oswego, N. Y., November 24, 1871, he received the degrees of bachelor of science from Syracuse University (1893), and doctor of philosophy (1897) from the University of Berlin. Following a year's study in the electrical engineering laboratory at the Technische Hochschule, Darmstad (1897–98), he returned to the United States as associate professor of electrical engineering in the college of liberal arts at Syracuse University. In 1902, when the college of applied science was established, he was appointed head of the department of electrical engineering, and in 1912 became dean of the college of applied science. He continued in that capacity until 1922, when he was appointed vice-chancellor, and since 1937 he has served as chancellor. At the 1942 commencement exercises of Syracuse University he was awarded the George Arents Medal. In 1938 he was awarded the honorary degree of doctor of laws by Colgate University. He is a member of the American Association for the Advancement of Science, American Astronomical Society, Phi Beta Kappa, Sigma Xi, and Tau Beta Pi, and has been active in the work of the Institute's Syracuse Section.

R. D. Sloan (A'17, M'28) acting dean, college of mechanic arts and engineering, and head of the electrical engineering department, State College of Washington, Pullman, has been appointed dean. Graduated with the degrees of bachelor of science in electrical engineering (1913), University of Montana, and electrical engineer (1921), Montana State College, he entered the testing department of General Electric Company, Schenectady, N. Y., and Pittsfield, Mass. From 1915–16 he worked on the construction and operation for the Great Falls (Mont.) Power Company. From 1916–22 he served first as instructor and then assistant professor of electrical engineering at Montana State College, Bozeman, excepting a period during World War I (1917–19) in which he served in the United States Navy. From 1922–23 he was assistant professor of electrical engineering, Yale University, New Haven, Conn., and in 1923 he joined the electrical engineering faculty of the State College of Washington, Pullman, as associate professor. In 1926 he received his full professorship, and became vice-dean of the college of engineering.

J. S. Hagan (A'20, M'31) formerly western railway sales manager, Thomas A. Edison, Inc., Edison Storage Battery Division, Chicago, Ill., has been appointed manager of the northwestern district, manufacturing and repair department, Westinghouse Electric and Manufacturing Company, La Grange, Ill. He holds the degree of bachelor of science in electrical engineering (1916) from Kansas State Agricultural College. He first joined the Westinghouse company in 1916, entering the graduate student course, and in 1917 was assigned to the railway section of the general engineering department. From 1917–19 he served with the United States Army, returning to the company at the close of World War I. In 1922 he was sent by them to Java in connection with the electrification of a railroad. From 1924–27 he was associated with the Baltimore and Ohio Railroad, and from 1927–35 he was head of the electrical department of the Central Railroad of New Jersey. In 1935 he entered the employ of the Thomas A. Edison company, as railway sales manager until his return to the Westinghouse company.

R. R. Robley (A'18, M'20) formerly assistant to the vice-president of the Portland (Oreg.) General Electric Company, has recently been appointed assistant to the president. Born May 31, 1875, in Walla Walla County, Wash., he received the degree of bachelor of science in electrical engineering from the University of Oregon in 1901. He has been associated with the Portland General Electric Company since 1904. He has occupied various positions in the operating department of the company, becoming superintendent of operation in the power and light department in 1927 and assistant to the vice-president in 1940. **F. R. Groch** (A'40) formerly junior engineer in the rates and statistics department, has been appointed assistant to the vice-president to succeed Mr. Robley. He received the degree of bachelor of science in electrical engineering from California Institute of Technology in 1930. Prior to his affiliation with Portland General Electric Company in 1940, he was associated with several electrical utility companies in California.

Donald Gunn (M'36) formerly assistant to the chief engineer, Pennsylvania Water and Power Company, Baltimore, Md., has been made chief engineer. Mr. Gunn joined the engineering staff of the company in 1930. Graduated from Georgia School of Technology in 1925 with the degree of bachelor of science in mechanical and electrical engineering, he gained his engineering experience with the Duquesne (Pa.) Light Company, the American Rolling Mills Company, and the Byllesby engineering and Management Corporation, Pittsburgh, Pa. **G. W. Spaulding** (A'24, M'32) assistant chief engineer, has been appointed superintendent of power. He received the degree of bachelor of science from Massachusetts Institute of Technology in 1921. In 1924 he became associated with the company as test engineer, and successively became chief of tests (1925), assistant to the general superintendent in charge of power studies and system planning (1928), and assistant chief engineer (1939).

D. W. Atwater (A'34) formerly manager of the commercial engineering department, Westinghouse Lamp Division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., has been appointed head of the company's newly created illuminating engineering department. He is in charge of planning for the application of recently developed light sources to the expanding lighting needs of the nation. He received the degree of bachelor of mechanical engineering in 1916 from Stevens Institute of Technology, and joined the General Electric Company, Harrison, N. J., as factory engineer in the Edison Lamp Works. From 1919–20 he served as specification engineer, Western Electric Company, New York, N. Y., and in 1920 joined the Westinghouse company. He has been associated with the Westinghouse company continuously since 1920, and was made manager of commercial engineering in 1934.

Bartow Van Ness, Jr. (A'23, M'35) formerly assistant to the chief engineer of the Pennsylvania Water and Power Company and the Safe Harbor Water Power Corporation, Baltimore, Md., has been appointed chief engineer of the latter corporation. Mr. Van Ness was graduated from Johns Hopkins University in 1921 with the degree of bachelor of electrical engineering, and from Massachusetts Institute of Technology in 1922 with the degree of master of science in electrical engineering. He has been with the companies continuously since 1922, and has worked on the Safe Harbor project from the preliminary estimate studies to its present state. He is responsible for the electrical engineering and electrical design of the power plant, as well as the single phase Conestoga substation for supply of power to the Pennsylvania Railroad. He has also been associated in the solution of numerous high tension interconnecting problems.

H. E. Becker (A'37) central-station department, Westinghouse Electric and

Manufacturing Company, San Francisco, Calif., has been appointed supervisor of the maintenance sales department for the Pacific Coast district. He was graduated from Leland Stanford University in 1922 with the degree of bachelor of arts in electrical and mechanical engineering. He first entered the employ of the Westinghouse company, East Pittsburgh, Pa., in 1922, in the student course in electrical engineering, and in 1923 was assigned to the central-station division. In 1925 he was transferred to the San Francisco office as sales engineer in the industrial division, and later was assigned to the Stockton, Calif., office to handle work of both central-station and industrial divisions. In 1927 he returned to San Francisco as sales engineer for the central-station division.

N. S. Hibshman (A'27, F'41) formerly associate professor of electrical engineering, Lehigh University, Bethlehem, Pa., has been appointed head of the department of electrical engineering at New York University, N. Y. He was born January 20, 1902, at Harrisburg, Pa., and received the degrees of bachelor of science in electrical engineering (1924) from Pennsylvania State College, and master of science in electrical engineering (1927) from Lehigh University. He was a member of the electrical engineering faculty of Lehigh University from 1920–42, becoming successively assistant professor and associate professor. He has served as AIEE vice-president representing the middle Eastern District, and is a member of Phi Kappa Phi, Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

L. T. Williams (A'27) division engineer, Southwestern Gas and Electric Company, Shreveport, La., has been named acting chief engineer of the general department. He received the degree of bachelor of science from Texas Agricultural and Mechanical College, and joined the company in 1924. He has been employed by that company since, except for a brief period with the Dallas (Tex.) Power and Light Company in the designing division. In 1938 he was made division engineer for the East Texas oil fields district and in 1939 was transferred to Texarkana, Tex., as assistant to the chief engineer of the company.

E. J. Rutan (A'20, M'29) formerly test engineer, technical service, Consolidated Edison Company of New York (N. Y.), Inc., has transferred to Chemical Construction Corporation, New York, N. Y. He had been associated continuously with the Consolidated Edison Company since 1919, working as test engineer in the test department, becoming superintendent in 1924, and later becoming supervisor of the test bureau. He was chairman of the AIEE technical committee on instruments and measurements during 1930–33, and has served on that committee since 1926, and the standards committee from 1933–42.

R. M. Smith (A'35) engineering manager, wiring device division, The Bryant Electric Company, Bridgeport, Conn., has joined Roller-Smith Company, Bethlehem, Pa., as assistant chief engineer. He received the degree of bachelor of science in electrical engineering from the University of Washington (1925) and was employed by Westinghouse Electric and Manufacturing Company, Newark, N. J., for 16 years as section engineer on relay design and application prior to his affiliation with The Bryant Electric Company. He has served on the AIEE committee on protective devices, and is the author of several technical articles.

W. P. Doolittle (A'24, M'30) industrial engineer, Kansas City (Mo.) Power and Light Company, retired recently. He was first employed in the power and lighting sales department of that company in 1904, and in 1905 was placed in charge of the department. From 1911–18 he was operator of a small private power and lighting plant which he purchased and installed on Isles of Pines, Cuba. In 1919 he returned to Kansas City Power and Light Company, and has been engaged with them continuously since then in the sale of service, power, and equipment.

Gerard Swope (A'99, F'22) honorary president of the General Electric Company, New York, N. Y., has been reappointed president of that company. He joined the General Electric company at Chicago, Ill., in 1893, and after service with the Western Electric Company, Chicago, Ill., and the International General Electric Company, he became president of the General Electric Company in 1922, remaining until 1940 when he retired.

W. B. Elmer (A'35) head of the distribution technical division, Boston (Mass.) Edison Company has joined the engineering staff of the Westinghouse Electric and Manufacturing Company, Sharon, Pa., to do research work. He was graduated from Massachusetts Institute of Technology with the degree of bachelor of science in 1922 and in that year was employed by the Edison Electric Illuminating Company of Boston (later the Boston Edison Company).

R. M. Cunningham (A'40) senior staff engineer, Bell Telephone Company of Pennsylvania, Philadelphia, has been transferred to the operating results division, American Telephone and Telegraph Company, New York, N. Y., where he is working on inventory and appraisals. He has been doing similar work with the Bell company since 1938.

S. A. Schelkunoff (M'34) consultant in electromagnetic theory, research department, Bell Telephone Laboratories, Inc., New York, N. Y., has been awarded the Morris Liebmann Memorial Prize by the Institute of Radio Engineers "for his contributions to the theory of electromagnetic fields in wave transmission and radiations."

J. M. Fluke (A'37) lieutenant (junior grade) United States Naval Reserve, Bureau of Ships, Navy Department, Washington, D. C., and formerly of the General Electric Company, Bridgeport, Conn., has received a special Merit Award from that company for his contributions to the design and manufacture of strip silver contacts.

H. W. Martin (A'40) sales engineer, estimating and engineering publicity department, Allis-Chalmers Manufacturing Company, Boston, Mass., was awarded a $100 prize by the Compressed Air Institute, Cleveland, Ohio, for a paper demonstrating the use of compressed air blasts for breaking circuits in high voltage lines.

L. G. Woodford (M'31, F'42) chief engineer, operation and engineering department, American Telephone and Telegraph Company, New York, N. Y., has been granted leave of absence to assume his duties as deputy director of procurement in the headquarters of the United States Army Services of Supply.

O. P. Cleaver (A'36) head of the illumination section, commercial engineering department, Westinghouse Lamp Division, Westinghouse Electric and Manufacturing Company, Bloomfield, N. J., has been commissioned a captain in the United States Army Engineer Corps.

A. C. Marshall (A'14, F'29) president and general manager, Detroit (Mich.) Edison Company, has been elected vice-president and a member of the board of lifetime trustees of the Horace H. Rackham Engineering Foundation, Detroit, Michigan.

George Sutherland (A'20, F'27) general stores manager, purchasing and stores department, Consolidated Edison Company of New York, N. Y., has been appointed War Production Board regional salvage manager for New York and New Jersey.

J. E. Jackson (A'26) district manager of the Appalachian Electric Power Company, Lynchburg, Va., has been granted wartime leave of absence to join the staff of the United States Office of Scientific Research and Development, Washington, D. C.

W. H. Matthies (A'26, M'29) director of switching development, Bell Telephone Laboratories, New York, N. Y., was recently elected a member of the executive committee of the Edward J. Hall chapter, Telephone Pioneers of America.

H. A. Walsh (A'30, M'31) electrical engineer, Doble Engineering Company, Medford Hillside, Mass., has been appointed business manager for El Paso (Tex.) Electric Company. He had been employed by the Doble company since 1923.

H. J. Chanon (A'33, M'41) electrical engineer, General Electric Company, Nela Park, Cleveland, Ohio, has been transferred to the company's South Pacific division, Los Angeles, Calif.

W. F. Kennedy (A'22) superintendent, meter department, New York and Queens

Electric Light and Power Company, Flushing, N. Y., has been assigned also the Brooklyn meter division.

R. E. Mathes (A'37) assistant division head, terminal facilities research laboratory, RCA Communications, New York, N. Y., is serving as a lieutenant in the United States Naval Reserve.

S. M. Sharp (A'26, M'42) former chief engineer of the Southwestern Gas and Electric Company, Shreveport, La., is now serving as captain in the signal corps of the United States Army.

OBITUARY

Leon Byron Woodworth (A'00, M'29) retired consulting engineer, Durban, South Africa, died May 29, 1942. He was born March 4, 1874, in Arcade, N. Y., and studied at Franklin Institute and Canasius College. After a six-month apprenticeship with General Electric Company, Schenectady, N. Y., in 1893, he joined the Buffalo (N. Y.) Electric Transit Company, in 1894, as construction superintendent, later becoming manager. In 1895 he resigned and left for South Africa, where he was engaged in constructing electrical plants. From 1898–1908 he was assistant mechanical and chief electrical engineer for the New Heriot Gold Mining Company, Johannesburg, excepting the period of the Boer War (1899–1902), during which he served with the British forces in the Royal Engineers. In 1909 he became assistant to the consulting electrical and mechanical engineer for H. Eckstein and Company, Johannesburg, retaining that position when the company became the Central Mining and Investment Corporation. He was employed by that company until his retirement in 1941, becoming sectional engineer in the electrical and mechanical department in 1923, and consulting engineer in 1939. In addition to his duties with the Central Mining and Investment Corporation, he was engaged in research work at the Rand Mines Mechanical Laboratory, Johannesburg, and served as engineering consultant for a number of mining and industrial plants. He was the holder of several patents on methods of ore separation. Mr. Woodworth was a member of the Institution of Electrical Engineers, England, the South African Institute of Electrical Engineers, and the Certificated Engineers, Union of South Africa.

E. Dean Tanzer (A'15) engineer, United Engineers and Constructors, Inc., Philadelphia, Pa., died June 11, 1942. Born October 11, 1889, in Lowville, N. Y., Mr. Tanzer received from Syracuse University the degree of bachelor of science in electrical engineering in 1911. Upon graduation he became an engineering apprentice with Westinghouse Electric Company, East Pittsburgh, Pa., and in 1912 was instructor in electrical engineering, Louisiana Industrial Institute, Ruston. After a brief period with Commonwealth Edison Company, Chicago, Ill., as engineer on central and substation design, he became instructor in electrical engineering, University Extension, City of Milwaukee, Wis., in 1913. From 1914–16 he was assistant professor of electrical engineering at Lafayette College, Easton, Pa., and from 1916–18 he held a similar position at Georgia School of Technology, Atlanta. In 1919 he became engineer in the transmission and distribution department, Philadelphia (Pa.) Electric Company. From 1927–30 he was consulting engineer with Day and Zimmermann Company, Philadelphia, Pa., and held a similar position with United Engineers and Constructors, Incorporated, from 1930 until his death. In addition he had been head of the electrical engineering department of Drexel Evening School, Philadelphia, Pa., since 1919. He was a member of the Transformer Oil Advisors, United States National Committee of the International Electrotechnic Commission, and was official delegate to the meetings of the commission in Bellagio, Italy, 1927, and Stockholm, Sweden, 1930. He was also a member of the Illuminating Engineering Society, the National Electric Light Association, the American Society for Testing Materials, and Tau Beta Pi.

Frank G. Frost (M'22) general superintendent, electric department, New Orleans, (La.) Public Service, Inc., died July 1, 1942. Born February 1, 1877, in Maltoon, Ill., Mr. Frost was graduated from the University of Illinois in 1901 with the degree of bachelor of arts in mechanical engineering. During 1901 he worked as draftsman for A. L. Ide and Sons, Springfield, Ill., and in 1902 became chief engineer of the Rorig Engineering Company, Columbus, Ohio. From 1904–07 he was chief draftsman for the Sheffield Car Company, Three Rivers, Mich., and from 1907–15 he was associated with Ford, Bacon and Davis Engineers, New York, N. Y., in various duties in Birmingham, Ala., Little Rock, Ark., and Houston, Tex. In 1915 he was appointed general superintendent for Houston (Tex.) Lighting and Power Company, and in 1918 became superintendent of power for the New Orleans (La.) Railway and Light Company. He worked continuously for that company and its successor, the New Orleans (La.) Public Service, Incorporated, from 1918 until his death, advancing to general superintendent of the electrical department in 1921. Mr. Frost helped organize the New Orleans section of AIEE in 1933, and was section chairman for the year 1937–38. He was chairman of the committees on meeting arrangements and general entertainment for the December 3–5, 1941 Southern District meeting held in New Orleans, and was chairman of the AIEE committee on civil protection in New Orleans at the time of his death. He was also a member of The American Society of Mechanical Engineers.

Harold Constad (A'35) managing director, Batwin Electric Motors, Ltd., London, England, died September 1940. He was born May 26, 1898, and studied at the Perse School, Cambridge, British Institute of Engineering Technology. During World War I (1914–18) he served with the Royal Army Service Corps in the mechanical section, and in 1919 he became electrical engineer for Moss Empires, Ltd., England. In 1925 he joined the electrical section of L. Constad and Company, Ltd., Engineers, Sheffield, and in 1930 he became managing director of Power Contracts, Ltd., London. He became director of electrical sales for the Batwin Electric Motors, Ltd., London, in 1939, and in 1940 was appointed managing director, a position he held until his death.

James Singleton Porter (A'35) sales department, Westinghouse Electric and Manufacturing Company, Oklahoma City, Okla., died May 2, 1942. Born October 17, 1899, in Lena, Miss., Mr. Porter received the degree of bachelor of science in electrical engineering in 1923 from Mississippi Agricultural and Mechanical College. Following graduation he joined the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa., remaining with the company until his death. His first year was spent in the graduate student course in Pittsburgh, and in 1924 he was transferred to the district sales office as sales assistant. Since 1925 he has served the Westinghouse Electric company in Oklahoma City, Okla., in the sales and application engineering department.

F. A. Calmus (A'29) Pacific Coast manager, Elliott Company, San Francisco, Calif., died August 2, 1942. Born March 1, 1894, in Marshalltown, Iowa, he received the degree of bachelor of science in electrical engineering from Iowa State College in 1917. In 1919 he entered the employ of Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa., and in 1921 he joined the Elliott Company, Kansas City, Mo., ultimately becoming manager. In 1928 he was transferred to the San Francisco office, as vice-president. He later became district sales manager. He was also a member of The American Society of Mechanical Engineers.

MEMBERSHIP

Recommended for Transfer

The board of examiners, at its meeting on September 24, 1942, recommended the following members for transfer to the grade of membership indicated. Any objection to these transfers should be filed at once with the national secretary.

To Grade of Fellow

Cleary, L. H., partner, Weschler and Cleary, Washington, D. C.

MacNeill, J. B., manager, Switchgear Engineering Department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Miller, J. H., assistant chief engineer, Weston Electrical Instrument Corporation, Newark, N. J.

3 to grade of Fellow

To Grade of Member

Austin, F. M., vice-president, Houston Lighting and Power Company, Houston, Texas.

Bass, N. I., supervisor of Western division, Houston Lighting and Power Co., Rosenberg, Texas.

Bender, D. S., field engineer, Bell Telephone Laboratories, Inc., New York, N. Y.

Blackledge, R. S., chief assistant designer, Veritys Ltd., Aston, Birmingham, England.

Bowman, N., district planning engineer, Detroit Edison Company, Detroit, Mich.

Bustard, W. B., electrical engineer, Headman, Ferguson and Carollo, Phoenix, Ariz.

Capon, A. E., electrical engineer, City of Burbank, Calif.

Casey, E. J., application engineer, General Electric Company, Philadelphia, Pa.

Clarke, T. C., district manager, Northern Electric Company Ltd., Vancouver, B. C.

Cole, F. H., owner, Cole Electric Company, Los Angeles, Calif.

Condon, E. S., president, Condon and Young, Inc., Los Angeles, Calif.

Davidge, R. C., office engineer, International General Electric Company, Schenectady, N. Y.

Dietz, W. F., assistant manager, Westinghouse Electric and Manufacturing Company, Washington, D. C.

Dixon, A. R., staff engineer, American Telephone and Telegraph Company, New York, N. Y.

Drake, E. F., electrical superintendent, National Paper Products Co., Port Townsend, Wash.

Dyer, C. E., general foreman, Pacific Gas and Electric Company, Santa Maria, Calif.

Fathauer, W., assistant chief engineer, General Electric X-Ray Corporation, Chicago, Ill.

Ferguson, F. H., superintendent, light and power, Puget Sound Power and Light Co., Bremerton, Wash.

Frantz, J. D., assistant superintendent, Northwestern Electric Company, Portland, Oreg.

Gates, S. E., manager, General Electric Company, Los Angeles, Calif.

Giesecke, H. W., assistant to electrical engineer, Consolidated Gas Elec. Light and Power Company, Baltimore, Md.

Goodridge, W. N., electrical designer, J. G. White Engineering Corporation, New York, N. Y.

Gunsburger, E., chief electrical design engineer, Midwestern Engineering and Construction Company, Tulsa, Okla.

Gustafson, O. A., central station engineer, General Electric Company, Los Angeles, Calif.

Hamilton, J. P., assistant electrical engineer, Tennessee Valley Authority, Wilson Dam, Ala.

Hartsell, H. W., engineer, Commonwealth and Southern Corporation, Jackson, Mich.

Hedges, L. B., chief load dispatcher, Bureau of Power and Light, Los Angeles, Calif.

Hewitt, C. D., engineer, Southern New England Telephone Company, New Haven, Conn.

Howard, F. M., superintendent, meter and service department, Mountain States Power Company, Casper, Wyo.

Johnson, V. E., sales engineer, Westinghouse Electric and Manufacturing Company, Milwaukee, Wis.

Kipp, E. B., meter instrument relay specialist, Westinghouse Electric and Manufacturing Company, Los Angeles, Calif.

Kirkish, J. J., engineer, Louis Allis Company, Milwaukee, Wis.

Logan, A., engineer and manager, The Dunoon and District Electricity Supply Company Ltd., Dunoon, Argyll, Scotland.

Mansfield, C. G., assistant underground engineer, Bureau of Power and Light, Los Angeles, Calif.

Myers, A. F., assistant engineer, Bureau of Reclamation, Bonneville-Grand Coolee Dam, Wash.

Oliver, R. C., electrical engineer, Black and Veatch, Kansas City, Mo.

Phillips, R. L., superintendent, Sterlington Steam Electric Station, Sterlington, La.

Rogers, W. T., safety and research consultant, Ebasco Services, Inc., New York, N. Y.

Rosenkraus, A. A., assistant electrical engineer, Underwriters Laboratories, Inc., New York, N. Y.

Russell, F. A., instructor, Newark College of Engg., Newark, N. J.

Sasscer, C. D., electrical engineer, Office of Chief of Engineers, Washington, D. C.

Schonborn, R. J., electrical engineer, Bureau of Power and Light, Los Angeles, Calif.

Smith, S. B., electrical engineer, Ebasco Services, Inc., New York, N. Y.

Sylvane, A. A., engineer in charge, Commercial Radio-Sound Corp., New York, N. Y.

Techienburg, H. C., electrical engineer, Mason and Hanger Company, Merrimac, Wis.

Tenney, G. C., editor and publisher, Electrical West, San Francisco, Calif.

Watson, G. G., electrical engineer, Bureau of Power and Light, Los Angeles, Calif.

47 to grade of Member

Applications for Election

Applications have been received at headquarters from the following candidates for election to membership in the Institute. Names of applicants in the United States and Canada are arranged by geographical District. If the applicant has applied for direct admission to a grade higher than Associate, the grade follows immediately after the name. Any member objecting to the election of any of these candidates should so inform the national secretary before October 31, 1942, or December 31, 1942, if the applicant resides outside of the United States or Canada.

United States and Canada

1. NORTH EASTERN

Blomquist, H. R. (Associate re-election), United Electric Railways Company, Providence, R. I.

Duryee, L. M. (Member), Connecticut Light and Power Company, Waterbury, Conn.

Nelson, R. A., Simplex Wire and Cable Company, Cambridge, Mass.

Thynell, G. M., Bristol Company, Waterbury, Conn.

2. MIDDLE EASTERN

Block, M. J., United States Navy Department, Bureau of Ships, Washington, D. C.

Brandenburg, H. V., Bureau of Yards and Docks, Washington, D. C.

Douville, E. L., G. L. Martin Company, Baltimore, Md.

Herbert, M. G., Cincinnati and Suburban Bell Telephone Company, Cincinnati, Ohio.

Jones, E. E. (Member), Stone and Webster Engineering Corporation, Williamsport, Pa.

Kern, K. C., The Baltimore Transit Company, Baltimore, Md.

Longwell, R. R., Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

Miner, J. D., Jr. (Member), Westinghouse Electric and Manufacturing Company, Lima, Ohio.

Omin, W. W., Navy Yard, Philadelphia, Pa.

Osborne, W. S., New York Shipbuilding Corporation, Camden, N. J.

Platt, L. R., Air-Track Manufacturing Corporation, College Park, Md.

Wandersleben, A. E., Electric Controller and Manufacturing Company, Cleveland, Ohio.

3. NEW YORK CITY

Barte, M. L. (Member), Nichols Engineering and Research Corporation, New York, N. Y.

Blackwedel, G. H. (Member re-election), Burns and Roe, New York, N. Y.

Brody, M. K. (Member), McCall Corporation, New York, N. Y.

Davies, R. J. (Member), E. J. White Company, Newark, N. J.

DeCarlo, C. J., C. H. Stevens Company, New York, N. Y.

Falvey, W. M., Wilputte Coke Oven Corporation, New York, N. Y.

Glaser, E. M., Square D Company, Elmhurst, N. Y.

Jorch, W. F., Roosevelt Aviation School, Mineola, N. Y.

Kay, E. T., Wilputte Coke Oven Corporation, New York, N. Y.

Malone, J. F. (Member), New York and Queens Electric Light and Power Company, Long Island City, N. Y.

Peters, R. C. (Associate re-election), Gibbs and Hill Incorporated, New York, N. Y.

Rayment, W. (Member), Stuyvesant High School, New York, N. Y.

Rose, D. J., Westinghouse Electric and Manufacturing Company, Bloomfield, N. J.

Ruscher, J. E., Westinghouse Electric and Manufacturing Company, Newark, N. J.

Whitaker, U. A. (Member), Aircraft-Marine Products Inc., Elizabeth, N. J.

4. SOUTHERN

Christenbury, F. L. (Member re-election), Criminal Court Building, Memphis, Tenn.

Davis, R. S., Florida Power and Light Company, Sarasota, Fla.

Hollman, C. W. (Member), Virginia Electric and Power Company, Richmond, Va.

Hollis, M. O. (Associate re-election), 3621 San Pedro, Tampa, Fla.

Lang, H. C. (Member), Giffels and Vallet, Inc., Norfolk, Va.

Riddick, A. G. (Member re-election), C. T. Patterson Company, Inc., New Orleans, La.

Romanowitz, H. A. (Member), University of Kentucky, Lexington, Ky.

Wasson, J. M., Southern Bell Telephone and Telegraph Company, Jacksonville, Fla.

Williams, C. H., Chesapeake and Ohio Railway Company, Richmond, Va.

5. GREAT LAKES

Brueck, H. L. (Associate re-election), 53 West Jackson Boulevard, Chicago, Ill.

Edwards, J. R., Delco Remy Corporation, Anderson, Ind.

Freezee, W. D. (Member), American Telephone and Telegraph Company, Chicago, Ill.

Lynette, H. A., II (Member), Mason and Hanger Company, Baraboo, Wisc.

Reed, E. V., F. Mattern Manufacturing Company, Chicago, Ill.

6. NORTH CENTRAL

Bird, E. F. (Member), The Mountain States Telephone and Telegraph Company, Denver, Colo.

Birkett, C. M. (Member), Steamboat Springs Electric Engineering Company, Steamboat Springs, Colo.

Colby, H. B., Public Service Company of Colorado, Denver, Colo.

Mayer, F. N., United States Army Air Base, Rapid City, S. Dak.

Rumohr, C. G., Public Service Company of Colorado, Denver, Colo.

Searle, G. W., Mountain States Telephone and Telegraph Company, Denver, Colo.

7. SOUTH WEST

Cooper, P. L., Jr., Southwestern Bell Telephone Company, Houston, Texas.

Courtney, G., Electric Supply Company, Galveston, Texas.

Hinton, J. F., American Telephone and Telegraph Company, St. Louis, Mo.

Landwehr, I. H., Union Electric Company of Missouri, St. Louis, Mo.

McDonald, W. C., Southwestern Bell Telephone Company, Houston, Texas.

Rothpletz, M. W., Rural Electrification Administration, St. Louis, Mo.

8. PACIFIC

Bishop, A. M., Navy Department, Mare Island, Vallejo, Calif.

Crow, J. R. (Member), Southern California Telephone Company, Los Angeles, Calif.

Elliott, J. L. (Associate re-election), 520 Pine Street, Redwood City, Calif.

Fleming, J. A., Sterling Electric Motors, Inc., Los Angeles, Calif.

Knopp, H. F., Electric Facilities Inc., Oakland, Calif.

LaPiant, O., United States Engineers, San Francisco, Calif.

Radcliffe, H. D., California Shipbuilding Corporation, Wilmington, Calif.

Rector, E. M., Basic Magnesium Incorporated, Las Vegas, Nev.

Tarran, L. (Member), C. C. Moore and Company, San Francisco, Calif.

9. NORTH WEST

Rohrer, D. D., Washington Water Power Company, Spokane, Wash.

10. CANADA

Ferguson, A. F., Hydro Electric Power Commission of Ontario, Burlington, Ont.

Hedley, F. H., Westinghouse Company Ltd., Vancouver, B. C.

Holmes, R., International Silver Company, Niagara Falls, Ont.

Metcalfe, C., Defense Industries, Limited, Nitro, Quebec, Canada.

Total United States and Canada, 71

Elsewhere

Badham, L. H. L. (Member), The Switchgear and Erection Co. (Pty) Ltd., Johannesburg, South Africa.

Bocuf, A., British Power Transformer Company Ltd., Queensway, Ponders End, Middlesex, England.

Fleming, G., Usina Electrica General Alvear, Mendoza, Argentina, S. A.

Kinnaird, W. R., Marlborough Electric Power Board, Blenheim, New Zealand.

Steward, C. E. (Member), Johnson and Phillips Ltd., Charlton, London, S E 7 England.

White, C. H., Public Works Department, Electrical Branch, Sydney, New South Wales, Australia.

Total, elsewhere, 6

OF CURRENT INTEREST

Salvage Program in Every Plant

A salvage program in every plant, factory, shop, or yard is the backbone of the War Production Board's campaign to put our national waste back into production. It is the job of American industry, says the American Industries Salvage Committee, to see that all broken down, dismantled, and unusable materials are made available for scrap, if our steel mills are to be sure of enough scrap to keep up the steel production for the planes, tanks, guns, and ships we need to win the war. Methods of organizing a scrap campaign that can be used effectively by any plant, regardless of size or type, are announced by the salvage committee.

The organization to operate an effective salvage collection need not be elaborate or costly. It works best when it is simple and unencumbered with extra officials and unnecessary steps. An able executive of the company heads the program as salvage manager. He works with superintendents and foremen in various departments, and he must be armed with ample authority to make decisions to scrap unused material.

To start the ball rolling, the foremen should make a survey of their departments and report to the salvage manager machines and equipment which are obsolete or out of active production. The salvage manager should make a written report of these findings, as a basis for action.

It is management's function to mark and send to the scrap heap equipment that is obsolete. After inspection, use this yardstick in coming to a decision: If a machine or other piece of equipment hasn't been used for three months, and if it can't be proved that it will be used in the next three, turn it over where it can be used—or scrap it. Either dispose of equipment in industry if there is a call for it, or put it to work as scrap for the weapons of war.

Once such equipment has been marked for scrap, a responsible shop man should supervise its dismantling and classification. The assortment may be made to yield valuable replacement parts for machines in operation. Cutting down the need for purchasing new parts will remove the plant from the competition for equipment.

No salvage campaign can be successful without the wholehearted co-operation of every person in the plant. Remember that even the most worth-while cause needs the proper promotion to put it across. The battle for scrap to keep our production going is dramatic enough to put over with a bang. Stunts, posters, billboards, and frequent mention in company publications or house organs are excellent vehicles for capturing and sustaining employees' interest in the program. In most plants, excellent talent can be recruited for this promotion from among the employees.

Workers should be urged to contribute suggestions and ideas for increasing salvage output. These may either be cleared through the foreman or written on slips and deposited in a suggestion box. Occasional rewards and incentives for outstanding co-operation in the salvage campaign will bring out employees' initiative. Workers can make or break a program. If their enthusiasm is enlisted and maintained, they will prove collaborators who will match the efforts of management.

Bins and containers—preferably displaying a poster or a slogan—should be placed in strategic spots throughout yards and plants. These serve as depositing places for production scrap, salvaged waste materials, and contributions which workers bring from their home. Separate containers for different metals, rubber, twine, and so forth, will save time sorting the material.

Scrap is of use to the war effort in direct proportion to the speed with which it is gotten back into production. Arrange regular daily or biweekly schedules for the various departments and sources of supply. The salvage manager should see to it that collections are turned in on time to a central collection depot in the plant. Select a definite date each week for shipment to a junk dealer, or have the salvage shipped by the company to the nearest collection point.

Remember that scrap bears no label. It is old jigs, dies, castings; or it is a ten-ton machine no longer being used. Waste metal, rubber, burlap, and other critical materials are valuable even in small amounts. Every pound of these materials can be salvaged by industry for war work.

Treat the factory to a house cleaning. What was junk six months ago has its place in the war effort now. Sort rubbish carefully. Salvage what can be used, and burn or otherwise dispose of the real rubbish that cannot. Keep the premises clear of debris. This is the only method by which it can be made certain that there is nothing further to be salvaged.

Every bit as important as salvaging vital materials is the need to conserve what we have. Use less by making better use of what we have. Get this message across to the workers. It will benefit our sons and relatives in the armed forces. By preventing spoilage and breakage, the material we work with can be turned against the enemy.

In order to co-ordinate the salvage campaign in the individual plant with the national effort, it is essential that regular reports on the amounts collected, according to classification, be delivered to the industrial salvage committee set up by the War Production Board in your community.

Above all, make clear to all personnel that until the day when we have actually turned out all the war equipment we need to smash the Axis, salvage and conservation are going to remain vital phases of our production. Unless our scrap is turned into weapons *now*, America will be fighting the war with one hand tied behind its back.

Get Out the Industrial Scrap

1. Head up the campaign by appointing an able executive of the company, armed with authority to act.
2. Use posters, illustrations, pay-envelope stuffers, and all other publicity means to enlist all employees in scrap campaign.
3. Comb plant and yards for dormant scrap and unusable and abandoned equipment.
4. Survey all plant equipment, particularly idle, standing, or discarded machines.
5. Classify and segregate scrap, and supervise its handling.
6. Make each foreman responsible for preventing spoilage and waste in his department.
7. Report promptly equipment which is obsolete. If equipment has not been used in three months, and it can't be proved that it will be used in the next three, turn it over where it can be used . . . or scrap it.
8. Salvage usable parts from equipment marked for scrapping.
9. Speed return of scrap to mills and refineries through existing channels. Report regularly on collections of scrap to the industrial salvage committee set up by the War Production Board in your community.
10. Enforce monthly rechecks in every department to find scrap material previously overlooked.

Need for Copper Is Urgent

Emergency requests for 500,000 pounds of copper a day are being received at the present time from war plants and the armed services, the inventory and requisitioning branch of the War Production Board announced recently. Transfer of copper from idle and excessive inventories to producers needing this critical metal is necessary if these requests are to be met so that manufacture of munitions, airplanes, and tanks can continue at peak production.

"Copper and copper base alloys are now being allocated from idle inventories into strategic war production at the rate of over 4,000,000 pounds a week," declared E. A. Tupper, chief of the inventory and requisitioning branch. "But while this is double the original estimate for this date,"

be continued, "the current needs of our vast war production machine are now so great that even this figure must again be doubled within the course of the next few weeks." By early September, approximately 29,700,000 pounds of copper and copper base alloys had been allocated from immobilized stocks to war production channels through the WPB copper-recovery program. Of this total 2,400,000 pounds were allocated for stockpiling to meet future anticipated demands for standard shapes and sizes of mill products; 6,300,000 pounds were reported and allocated as scrap; 9,300,000 pounds were allocated, or known to have been moved for use in existing form, and 11,700,000 pounds were allocated to brass mills and ingot makers for remelting.

"Over 14,000 firms have reported a total of 111,000,000 pounds of idle and excessive inventories of copper and copper base alloys. Much of the copper reported has been offered for voluntary sale at the government's prices. That which the owner refuses to sell but which is nevertheless needed for war production will be requisitioned," Mr. Tupper declared.

A special unit from the copper branch of WPB has been set up in the offices of Copper Recovery Corporation, 200 Madison Avenue, New York, N. Y., to locate copper in the forms needed, and to redistribute it to war plants urgently requiring it because of unforeseen material shortages, plant breakdowns, receipt of new war orders, or other emergencies. In most of these emergencies, the war plant cannot wait for receipt of the needed shapes from its regular source of supply.

Ten Ways to Save Critical Materials in Distribution Systems

Tons of critical materials, particularly copper, can be saved by following these ten principles in installing war-plant power-distribution systems, according to H. V. Erben, manager of General Electric Company's central-station department:

1. Calculate as accurately as possible what the *actual* load will be and design the system to carry only that load—not on the basis of connected load.

2. Keep to the practicable minimum the distance over which the electric power is to be carried.

3. Transmit power at the highest practicable voltages and bring the high-voltage distribution as close to the load as possible.

4. Correct for low power factor at a point as close to the reactive load as possible.

5. Use compact, standard equipments. This not only saves copper, time, and money but also makes possible quick replacement in case of trouble.

6. Arrange layouts to limit circuit-breaker interrupting requirements to the optimum values, thus saving copper in busses and circuit breakers.

7. Use three-phase power transformers wherever feasible.

8. Use forced cooling on power transformers wherever practicable.

9. Select cables with a type of insulation that will permit maximum load per unit of copper.

10. Limit the number of cables per duct bank to the minimum to avoid loss of current-carrying capacity.

WPB Urges Maximum Use of All Available Electric Motors

Extensive use of secondhand electric motors and controls, utilization of full service factor of electric equipment, and design simplification are recommended by the electric motors and control section, general industrial equipment branch, of the War Production Board, as aids in conserving critical materials. Operators who have available secondhand motors or who could make effective use of them should write to the electric motors and control section for assistance in locating or placing such equipment.

With the present wartime material allotment to the electric motor and control industry, it is difficult if not impossible to make deliveries on any orders except those for the armed services and most vital war plants, which utilize about 90 per cent of the industry's production. However, use of secondhand standard electric motors and controls—of which there is an ample supply available in dealers' hands and in manufacturing plants, according to the WPB—would effect immediate delivery of these orders.

According to the electric motors and control section, motors today do not break down because of overheating resulting from overloading, but rather because of mechanical failure. Therefore, where new motors and control are required because of their special characteristics, it suggests that all purchasing agents, engineers, architects, and consultants, concerned with the operation, design, or application of electric motors and control, follow out, to the best of their ability, the following recommendations:

WPB Recommendations

SIZE OF MOTORS

1. In applying motors, determine with maximum possible accuracy the horsepower required. This should be preferably obtained by test, or, in the event that this is impossible, by accurate calculation, or by careful comparison with known power requirements of similar apparatus.

2. When applying open-type a-c continuous rated 40 degrees centigrade motors, where the motor rated voltage is maintained, and where the ambient temperature is usually substantially below 40 degrees centigrade and will only occasionally, or for short periods, equal or slightly exceed 40 degrees centigrade, select the standard horsepower rating which is not substantially more than 80 per cent of the horsepower determined in accordance with recommendation 1.

Example: The required horsepower, as determined in item 1, is 9.3; 80 per cent of 9.3 equals 7.44, so select a standard 7.5-horsepower motor.

3. When applying a motor a-c or d-c rated on a 50 degrees centigrade or 55 degrees centigrade basis, where the motor rated voltage is maintained, and where the ambient temperature is usually substantially below 40 degrees centigrade and will only occasionally or for short periods equal or slightly exceed 40 degrees centigrade, select the standard horsepower rating which is not substantially more than 91 per cent of the horsepower determined in accordance with recommendation 1.

4. After selecting a motor in accordance with recommendations 2 and 3, torque and operating speed should be checked to assure their adequacy.

5. When applying an open-type continuous rated 40 degrees centigrade d-c motor in a location where the ambient temperature is usually substantially below 40 degrees centigrade and will only occasionally or for short periods equal or slightly exceed 40 degrees centigrade, select the standard horsepower rating which is at least 87 per cent of the horsepower determined in accordance with recommendation 1.

SELECTION OF MOTOR TYPES

The type of motor selected shall be of the simplest mechanical and electrical design, which can be used to accomplish economically the purpose for which the motor is purchased. Where operating conditions permit, the motor should meet these specifications:

1. Open type rather than protected.
2. High speed instead of low speed.
3. Single speed rather than multispeed.
4. Single winding rather than two winding where multispeed motors are essential.
5. Alternating current instead of direct current where a-c power is available.
6. Squirrel cage instead of slip ring.
7. Single voltage only.
8. D-c adjustable-speed motors should have a lesser speed range than formerly.

SELECTION OF MOTOR CONTROLLERS

1. The wiring of all controllers should be specified as following the shortest possible route consistent with the avoidance of electrical and mechanical interferences. This will result in approximately 30 per cent reduction in the amount of copper wire used.

2. When controllers are built to order for a specified horsepower, busses, terminals, and wiring should be specified in a size no larger than the minimum required by the application for which the controller is designed.

3. No controllers should be specified of a capacity in excess of the minimum required for the application.

4. No equipment or device should be specified for a controller which can be eliminated without causing severe operating hazards. This equipment includes indicating lamps, special name plates, instruments, test receptacles and jacks, extra terminals, special locks, and items for the improvement of appearance. If specifications are cut to the minimum for successful

operation, many tons of critical material will be saved.

5. Control circuit wiring should be specified in a size no larger than the minimum required to carry the current and to insure reliable and safe operations.

6. Controllers should not be specified with finishes containing critical materials unless these finishes are absolutely necessary to maintain operation of the controller.

7. Color coding of controller wiring should not be specified, unless absolutely necessary. Color-coding specifications force manufacturers to carry larger stocks of wire than necessary if one color wire is used.

8. Control circuit transformers should not be specified, unless the line voltage is higher than 600 volts, or unless suitable pilot devices of adequate voltage rating are not available.

9. Control circuit fuses should not be specified if the control transformers have less than a 2,200-volt primary winding or if the control circuit is direct current.

10. Where full voltage starters are available, and, if motor design will permit, reduced voltage starters should not be specified, unless torque must be limited, or if system capacity makes full voltage starting impossible.

11. If manual controllers of suitable ratings are available, magnetic controllers should not be used, except where pilot devices are essential to the operation controlled or where lack of under voltage protection would result in definite danger to human life.

ELECTRICAL LAYOUTS

1. For new plants or extensions the utlization voltage should be restricted to 440 volts, alternating current, except where motors 100 horsepower and larger are used, in which case the voltage should be 2,200 volts or more. (This means that all integral horsepower a-c motors shall be supplied at 440 volts.)

2. No auxiliary or reserve busses or their attendant equipment should be provided.

3. Network distribution systems should not be used unless they show an over-all saving in critical material.

4. No equipment of any kind should be installed to provide for future loads or extensions.

5. No duplicate feeds or loop feeds should be used if any appreciable amount of material is required above that necessary for a single radial feeder.

6. All busses and feeders should be tapered as to size where long runs are used with loads being taken off along the run.

7. Requirements in all cases should be based on demands after load factor is considered, and all equipment specified so it will be loaded as near name-plate rating as possible.

EQUIPMENT RATINGS NOT TO EXCEED LOAD REQUIREMENTS

1. No electric motor and control should be purchased for any use unless reasonable effort has been made to obtain used or secondhand equipment, unless the maximum number of shifts are used, or unless reasonable effort has been made to adapt to the application idle equipment in the possession of the user.

2. No electric motor and control should be purchased for replacement of existing equipment for reasons of breakdown, damage, or obsolescence, unless reasonable effort is made to keep equipment in operating condition by installation of renewal parts or a reasonable amount of maintenance work.

3. No electric motor or control should be purchased in a size larger or of more complex design and construction than is required by the minimum operating conditions.

Substitute Materials Discussed by Alvah Small Before Contractors

The development of new wartime substitutes to replace critically scarce materials in electrical equipment was the subject of an address by Alvah Small (M'37), president of Underwriters' Laboratories, Inc., before the National Electrical Contractors Association in Bigwin, Ontario, recently.

Naming critical materials that have been restricted by priorities and the possible substitutes being tested to replace them, Mr. Small pointed out that the Underwriters' Laboratories is co-operating by putting into effect necessary changes in its requirements to recognize substitutes promulgated in emergency alternate specifications of the Federal Specifications Board. The provisions of Underwriters' Laboratories' Standards for Electrical Equipment have been identical with those of the United States FSB for like products for several years, he said. The substance of Mr. Small's address is reflected in the following paragraphs.

Demands for the consideration of substitutes were made of Underwriters' Laboratories, Inc., as early as the spring of 1941. Priorities controlling or limiting the use of zinc as a corrosion protective material required action with respect to coatings of raceways and of outlet and distribution-center hardware. Existing requirements were relaxed for the duration, so as to recognize enamel and paint finishes or to accept lesser thicknesses of zinc for coatings. Next, limitations on the use of cadmium and chromium made it necessary to accept, for the duration, phosphate treatments of the surface finishes of iron or steel parts; in most cases as a first or preparedness step for a final lacquered or paint finish, in other cases in preparation for the thinnest possible electrodeposited metallic finish.

MANY FSB AND UNDERWRITERS' REQUIREMENTS IDENTICAL

Always a large user of building materials and equipment, the United States early in 1941, perhaps even previously, became the biggest consumer of them. Consequently, the Underwriters' Laboratories practice of changing its requirements to meet the needs of the FSB was a practical plan of procedure, because the government had become the building industry's biggest customer, and because, in practically every case, the Federal Specifications Board determined upon changes that it announced only after conferences with the industry. Electrical equipment is naturally included in the catalog of Federal Specifications so modified. To some extent this was a "thoroughfare" routine, and Federal Specifications Board has adopted and announced changes that had already been published by Underwriters' Laboratories after being determined according to its "open-forum" program. Many requirements identical with those of the Underwriters' Laboratories, are merely a reference to the chapter and verse of an Underwriters' Laboratories' Standard.

The classification of aluminum as a critical material had early and due effect upon Underwriters' Laboratories' requirements because of changes demanded by the Office of Production Management in approved formulas for zinc-base die castings. For a while it seemed doubtful if recognition of these useful parts could be continued while the attainment of even minimum requirements for safety in performance was secured. It developed, however, that steam-bath tests provided an acceptable control while this difficulty continued. Many instances of prompt acceptance of substitutes for sheet aluminum are on record. Cotton-base phenolic composition for blades of electric fans is one of these instances.

The shortage in tin, particularly since Pearl Harbor and Singapore, required consideration of lower grades of brass in various parts and uses and promoted the use of a previously recognized substitute for the coating of rubber-insulated copper conductors in wires and cables. Mixtures for solder with lower tin content are recognized for many applications.

The limited supply of nickel made this metal a critical material early in the defense period. Once it was doubtful if nickel would be allowed for use in the bimetal elements that have so many safeguarding applications for temperature control, not only in electrical services but in many other fields. Its use in heating elements seems to be out in any event, but, fortunately, up until now, ways have been found to permit its use for bimetal elements of controls.

Plastics of various types and kinds were well established in electrical and other fields of application long before the preparedness and defense-program periods. In 1938–39 the thermoplastic type of synthetic insulation was developed and given generous recognition for conductor coverings. Unfortunately, up until now, priorities have limited its general availability as a wartime substitute.

More than a year ago requests were first

received that brass-plated steel be recognized instead of solid brass as a material for the wire-binding screws in lampholders, switches, and receptacles.

The senior electrical contractors will recall that, because of the copper shortage, steel parts, copper- or brass-plated, were accepted for panelboards, panelboard switches, and other products during World War I. Experiences, due to corrosion, heating, and maintenance troubles, makes one understand the reluctance of the laboratories to repeat this step and the troubles of the previous emergency. Recently it became necessary to take this step in order to assist in the conservation of copper and copper-bearing alloys, and now emergency alternate standards or requirements are in effect permitting the substitution of steel, plated or otherwise protected against corrosion, in the assembly of current-carrying appliances unless the actual part is involved in the making and/or breaking of a circuit. In addition, the Laboratories is conducting a research to determine what will be the performance of iron or steel, plain or plated, when substituted for parts actually involved in the current-interrupting function. It may be that the corrosion protection accomplished on stamped steel parts will function as desired until replacement can be made after victory. Such replacements will probably be required, particularly in seacoast areas within shorter periods, so that it may be wise to plan for replacements before the end of the war.

In the interval between Pearl Harbor and the fall of Singapore, requests were made for the lowering of Standards for rubber compounds in building wire insulation. After Singapore it was, of course, obvious that it had become the duty of everyone to conserve rubber in every possible way. Underwriters' Laboratories' requirements for the performance of rubber insulations in the oxygen-bomb test were modified to permit the use of much less new crude rubber in compounding.

Shortly after Singapore, the War Production Board found it necessary to conserve rubber by refusing permission for its use in the all-rubber type *POSJ* flexible cords employed with ordinary types of portable appliances. The type *PO*-64 flexible cord now substituted and recognized, in view of this limitation order, has perhaps the minimum positive value of factor of safety as well as of appearance and of general consumer and user satisfaction.

GUIDED BY NATIONAL ELECTRICAL CODE

In considering proposed substitutes for electrical goods, Underwriters' Laboratories is guided by the provisions of article 110—general—of the National Electrical Code. Sections 1113–1117 inclusive, in particular, apply; with section 1115 as the lead-off item of the group:

"1115. General Plan of Investigation. Materials devices, fittings, apparatus, and appliances designed for use under this code shall be judged chiefly with reference to the following considerations which also determine the classification by types, sizes, voltages, current capacities, and specific uses:

(*a*). Suitability for installation and use in conformity with the provisions of this code.

(*b*). Mechanical strength and durability, including, for parts designed to enclose and protect other equipment, the adequacy of the protection thus provided.

(*c*). Electrical insulation.

(*d*). Heating effects under normal conditions of use and also under abnormal conditions liable to arise in service.

(*e*). Arcing effects."

Changes that have been made in the National Electrical Code are reflected in the operations of Underwriters' Laboratories. For example, the new so-called type *EI* building wire is being accepted in nonmetallic sheathed cable, and the type *EI* wire itself is to be labeled as an emergency for-the-duration substitute for rubber-covered wires in exposed dry locations.

Donald Nelson's "bare-bones" policy that, for the duration, construction of new facilities be "of the cheapest temporary character" with structural stability only sufficient to meet the needs of the service which the structure is to fulfill during the period of its contemplated war use is a challenge to us to effect the maximum economies of materials and of manpower, and, at the same time, where safeguarding life, property, products, and material is involved, not to lower our standards below the minimum of normal times. To preserve at least these minimum standards of safety is the Underwriters' Laboratories' objective in the consideration of wartime substitutes.

Industry Urged to Plan for Man-Power Replacements

Advising industry to plan now for the loss of employees through the increasing need for military man power in the United States, Major General Lewis B. Hershey, director of Selective Service, pointed out in a recent statement that every employer should make a prompt inventory, appraisal, and analysis of the man power in his own plant. "In order to keep production going and at the same time furnish men for the armed forces, industry should now establish an orderly replacement program," he said. Essential substance of his statement follows.

In order to secure temporary deferments for essential men while training women, young men, older men, men physically handicapped, or those with a high degree of dependency, the employer should know the fundamental principles in the operation of his local Selective Service Board. Each employer should know how many men on his pay roll are between the ages of 20 and 45. He should investigate the classification of every one of those men. On the basis of such an inventory he should prepare to train men for the replacement of those who must necessarily enter the armed forces in order that the United States have the sort of army which can win the war.

DEFERMENTS TEMPORARY

Deferments, granted so that employers may train women or men not liable to early induction, are temporary deferments; they cannot exceed six months and in many cases may be for only thirty, sixty, or ninety days. The United States Army today has to train a bomber pilot within a period of eight months to operate a very technical machine with an instrument board which puzzles an expert. Industry, therefore, should not assume that it can take two or three years to train men for industrial tasks not nearly so complicated.

The fundamental purpose of every deferment of a registrant is to allow an employer to train a replacement worker. Only in rare instances can an employer expect to have temporary deferments continued for more than the six months period. This is possible only in cases where an abnormally long period of training is required for a replacement.

Employers may seek the deferment of their necessary men with or without their consent by the method outlined as follows.

On page 3 of the Selective Service questionnaire (form 40) which is sent to each registrant before he is classified, is the following:

Instructions. If your employer believes that you are a necessary man in a necessary occupation, it is his duty to fill out form 42A requesting your deferment. You may also attach to this page any further statement by yourself which you think the local board should consider in determining your classification. Such statement will then become a part of the questionnaire.

This is on all the questionnaires distributed during the past six months. The fact that the Selective Service system now specifically mentions the filing of form 42A as the manufacturers' duty, is a clear indication of the Selective Service system view on the responsibility of each employer in this matter. The employer can secure form 42A at the local board which will consider the employer's request when the form is properly filled out and signed. Only when an employee is working in a critical occupation within an essential industry should form 42A be filed for his occupational deferment.

If such a request should be denied because the man, after consideration of the claims offered for him, is thought to be not indispensable to the company's operation, and is needed more urgently in the armed services, the local board will inform the employer of its refusal to give an occupational deferment. The local board does this by sending to the employer, at the same time it notifies the registrant of his classification, form 59.

APPEAL POSSIBLE

There are ten days after form 59 is mailed by the local board to the employer during which the employer can appeal the registrant's case. The registrant will not be ordered to report for induction during this ten-day period.

In order to make an appeal, the employer simply has to sign his name to form 59 which he has received, and return it to the local board. In case the form 59 is not received from the local board, any written request is considered a valid appeal. When form 59 is returned by the employer the appeal procedure becomes automatic. All necessary forms are available at the local board in the employer's immediate vicinity

or at the office of the state director of Selective Service.

If the local board and the appeal board deny the appeal for the occupational deferment of a key man, the employer may then bring the matter to the attention of the state director at the State Selective Service headquarters, with the request that the case be reopened or appealed by him to the president.

THE EMPLOYER'S DUTY

A double duty rests upon the employer. He should personally know what his manpower situation is. He should not allow a minor employee to decide whether or not he is necessary in industry. The employer who delegates the task of filing a request for deferment to a clerk, the executive who does not make a complete inventory of his whole plant today, is negligent. Likewise, the employer who files requests for deferment of men who can be replaced by women or others, is keeping reinforcements out of an army which is battling for us all. The employer engaged in essential war production who has been required to expand his plant and who then fails to request deferment for his key men is also negligent. Employers are requested not to ask for deferments for any men who can be replaced by training another individual not likely to be eligible soon for service in the armed forces. On the other hand, employers should make requests for deferment for any man whose immediate going into the armed services would retard production of vital war material or other services essential to the war effort, or who is needed to maintain national health or safety.

Power Units Built for Synthetic Rubber Plants

Electrical apparatus for plants which will convert petroleum and alcohol derivatives into synthetic rubber, including steam turbine generators, are reported to be under construction by both General Electric and Westinghouse Electric and Manufacturing Companies. The abundance of high-pressure steam required for the production of butadiene and styrene, principal constituents of Buna *S* rubber, will enable the new chemical plants to generate their own electric power as a by-product. The steam will be used first to drive the turbine generators and then in the chemical processes.

Steam at a pressure of 750 to 850 pounds per square inch will pass from boilers to a steam turbine which will be coupled to an electric generator. Leaving the turbine at about 175 pounds pressure, the steam will then be used in the plants' chemical processes.

Part of the electricity will supply the motors and lights in the chemical plants, as well as in the adjacent co-polymerization plants in which the chemicals are combined to make rubber. Since the power generated will be much more than required by the chemical and rubber plants, the surplus will be diverted into regular public utility lines to help supply other war industries.

New Electric-Power Capacity Curtailed to 5,500,000 Kw

New power-generating capacity for completion in 1942, 1943, and to a limited extent early in 1944 has been scaled down to 5,500,000 kw, as opposed to the previous 9,600,000-kw program extending through 1945, according to latest revisions of priority ratings announced by the War Production Board. The aim of these new revisions is to convert manufacturing facilities to war production as quickly as possible, by rushing to early completion all utility projects essential to the war program, and by preventing the remaining projects from competing with military needs for critical materials. This new ruling means the halting of some projects now in construction and the continuance of others on a low-rated basis only. The decisions followed a comprehensive review begun last spring of the electric-utility-construction program from the viewpoint of the power-supply and requirements situation.

Of the 5,500,000 kw to be provided, 3,400,000 kw is in private utility projects, mostly steam, and 2,100,000 kw in public projects, mostly hydroelectric. Projects which have been given the higher priorities are designed to assure supply for war and indirect war production as now planned, with a small margin of capacity to provide for possible additional war production not now included in the munitions program. Assignment of units has been made on the basis of the needs of reasonably unified areas rather than strictly by systems.

Projects totaling 1,890,000 kw—previously scheduled for installation in 1943–45 as part of the program for Federal generating projects—are being reduced to low ratings, or are being held to their present low-rated or nonrated status. Work on low-rated projects may be continued, but only to the extent that it does not compete

More Power for War Plants

Westinghouse Photo

A 108,000-kw waterwheel generator, weighing 1,000 tons and measuring 45 feet in diameter and 24 feet high, being lowered into position in the powerhouse at Grand Coulee Dam, Wash.

for critical materials and equipment needed for direct war uses. For the most part, these Federal projects are hydroelectric developments.

ELECTRIC-SYSTEM EXPANSION ALSO CURTAILED

Further construction of electric power and light projects permitted under prior authorization with respect to projects 40 per cent complete on December 5, 1941, has been halted by WPB. The action, however, does not affect the construction of important war projects that have been or may be specifically authorized by WPB.

The new ruling removes authority to complete construction projects 40 per cent complete on December 5, and provides that there may be no additions or expansions to electric systems except as specifically authorized by the Director General for Operations of the WPB. It applies alike to both public and private utilities.

Manpower Commission Reports on War Use of Colleges

A report on recent developments in the utilization of colleges and universities in furthering the war effort was released August 28 by the War Manpower Commission. The report was prepared by the WMC special committee on the utilization of colleges and universities for the purposes of the war; personnel of this committee consists of: Edward C. Elliot, president, Purdue University, chairman; James B. Forrestal, Undersecretary of the Navy, Major General Lewis B. Hershey, director, Selective Service, G. H. Dorr, special assistant to the Secretary of War, Arthur S. Fleming, Civil Service Commission, and Wendell Lund, labor supply division, War Production Board.

Among the various items considered by the committee in preparing the report was the official statement of the Second Baltimore Conference of officers of institutions and organizations of higher learning, held July 15–16, 1942 (*EE Sept. '42, p. 490*). Essential substance of the report follows.

The members of the committee, mindful of the patriotic anxiety of the leaders of higher educational institutions state that these institutions shall have opportunity completely to perform their duties at this critical time. Furthermore, the members of the committee are confident that these institutions may be relied upon to respond willingly and energetically to the realistic needs growing out of the grim urgency of the war situation.

The utilization of the resources of materials and man-power of the United States for the armed services, war production, and for supporting war efforts depends on the immediate and developing war situation. Plans which are made today for the use of these resources must be flexible enough to meet the changing requirements of the war program.

The principal resources of colleges and universities for war purposes are their trained faculties and their physical facilities. The use of these resources will be determined by and should be adapted to the military needs of the nation.

All branches of the armed services are now using certain of the resources of the colleges and universities with the active co-operation of the institutions. The nature and the extent of this use must necessarily depend upon the need in the conduct of the war.

Any adequate plan designed to make effective use of colleges, universities, professional, and technical schools must be based upon the following considerations:

1. All students, men and women, must be preparing themselves for active and competent participation in the war effort and supporting civilian activities. This basic proposition will, of course, be accepted and understood by the institutions, by the students, and by the general public.

2. All able-bodied male students are destined for the armed forces. The responsibility for determining the specific training for such students is a function of the United States Army and Navy.

3. For those students, men and women, who are not to serve in the armed forces, there should be developed through the War Manpower Commission plans of guidance which will help the students to determine where they can make the most effective contribution to the war effort, including essential supporting activities. The War Manpower Commission should also make plans for the instruction of those for whom further training is necessary to enable them according to their qualifications to make their most needed contributions to the support of the armed forces.

4. Any plan for student war training must take into consideration the possibility that the Selective Service Act may be amended so as to lower the age of liability for service to 18 years.

5. All those colleges, universities, professional, and technical schools assuming direct responsibility for the training of students for war purposes must be prepared to readjust their instructional programs and procedures so as to enable them promptly and efficiently to meet the new and varying needs of the war.

6. Throughout the preparation for wartime services provision should be made for securing the complete physical fitness of students.

7. In order to avoid misunderstanding, students should recognize that the exigencies of the war do not make it possible to assure any student that he will be permitted to remain in the institution for any specified period of time. Furthermore, it should be recognized that it will not be possible prior to the opening of the academic year 1942–43 to formulate the details of some of the plans for the utilization of institutions nor to provide for the implementation of such plans.

8. The above plans for the war training of students do not contemplate any Federal subsidy to institutions.

9. To qualified students whose additional training is required for the war effort, financial assistance should be made available to permit them to receive that training.

10. The division of professional and technical personnel of the War Manpower Commission will proceed immediately to function as a central agency to assemble information from the government departments and higher educational institutions concerned and confer with them as to plans and procedures for the utilization of the facilities of the institutions and the adjustment of their programs for effective participation in the war effort.

Technical-Personnel Requirements to Be Checked by USES

Business establishments engaged in war production are going to be told within the next few weeks where and how they can obtain chemists, engineers, metallurgists, and other professional and scientifically trained men, Paul V. McNutt, chairman of the War Manpower Commission announced August 10. He said that representatives of the United States Employment Service had been instructed to find out how many employees of this type war-production plants will require before the end of the year and during 1943.

With this information in hand the USES, Mr. McNutt explained, can draw upon the country's largest registration of technically trained persons, the National Roster of Scientific and Professional Personnel. This roster, to which are now being added the names of the scientifically and professionally trained persons who have registered for military service, has been placed under the direction of the War Manpower Commission.

President of GE Named WPB Vice-Chairman

Charles E. Wilson, president of the General Electric Company, Schenectady, N. Y., has resigned to become vice-chairman of the War Production Board. In that capacity he will act as chairman of the newly organized production executive committee, which is composed of officials of the Army, Navy, and Maritime Commission and which is to have control of the production of military supplies. Mr. Wilson is succeeded as president of the General Electric Company by Gerard Swope (F'22) former honorary president (see Personal item on page 532 of this issue).

In the absence of Philip D. Reed, chairman of the board of directors of the General Electric Company, who is also in the service of the United States Government, Owen D. Young, honorary chairman, has been appointed acting chairman.

New WPB Director of Operations Announced. Ernest Kanzler, former deputy chairman on program progress, War Production Board, has been appointed director of general operations, according to Donald M. Nelson, chairman. Mr. Kanzler, who will have under his supervision all WPB operations carried out through industry and materials branches, succeeds Amory Houghton. Prior to his affiliation with the WPB, he was president of the Universal Credit Corporation, Detroit, Mich., which he founded in 1928, and had served for many years as vice-president in charge of production for the Ford Motor Company. In January 1942, he became chief of the WPB automotive branch with headquarters in Detroit, and in March 1942 he was appointed regional director of the WPB in Detroit. He was in direct charge of WPB activities in connection with conversion of the automotive industry.

Salvage Manual Available. A "Salvage and Scrap Material Manual for the Utilities" has been prepared by the utility unit, industrial salvage section, conservation division of the War Production Board, for

the information and use of utilities in their salvaging and scrap operations. It was prepared from procedures furnished by several utility companies and is a compilation of information on methods of salvaging materials for reuse and handling scrap. The manual contains an alphabetical listing of salvageable materials with descriptions of rehabilitation procedures and an assembly of scrap-material specifications.

INDUSTRY . . . . .

Positions to Be Filled Through Civil Service Examinations

Notice of the following positions, which will be filled through civil service examinations, is published here as a service to members of the Institute. Application forms and full information as to requirements for examinations may be obtained from the secretary of the Board of the United States Civil Service Examiners at any first- or second-class post office, or the United States Civil Service Commission, Washington, D.C.

Junior Physicist. $2,000 a year salary. No age limits. To qualify for the position, applicants must already have completed, or complete within six months after filing applications, a four-year college course including 18 semester hours in physics. Applications will continue to be accepted until the needs of the service have been met. No written tests are required.

Technical Assistant. Salaries range from $1,440 to $1,800 a year. The examination contains three optional branches: engineering, metallurgy, and physics. To qualify for the $1,800 positions, the applicant must have completed three years of college study. For the $1,600 positions, two years of college study is prescribed, and for the $1,440 positions, one year of college study is prescribed. Provision is made for the substitution of appropriate war-training courses for college hours in any optional branch. No written tests are required. Applications are not desired from persons engaged in war work unless a change of position would result in the utilization of higher skills possessed by the worker.

Westinghouse Launches New Lighting Activity. Application of recently developed light sources to the expanding lighting needs of the nation will be studied by the newly created illuminating engineering department of the Westinghouse Lamp Division, which will be headed by D. W. Atwater (A'34) former manager of commercial engineering (see page 531 of this issue). The new organization will plan for postwar as well as present expansion in the use of fluorescent, mercury vapor, and other light sources.

1942 Power Show Location Changed. The 15th National Exposition of Power and Mechanical Engineering, previously scheduled for Grand Central Palace, November 30 to December 5, 1942 (*see EE, Sept. '42, p. 493*), is to be held at Madison Square Garden, November 30 to December 4, according to a recent announcement. The change was made necessary by the fact that the United States Army has taken over the exposition floors for the duration of the war for use as an induction center.

OTHER SOCIETIES .

SPEE Awards Lamme Medal

The Society for the Promotion of Engineering Education has awarded the Lamme Medal for Achievement in Engineering Education to Roy A. Seaton, dean of the division of engineering and architecture, and director of the engineering experiment station, Kansas State College, Manhattan, Kansas, "for his leadership in engineering education . . . . for his service to his country through the development of emergency training in engineering in time of war, and for his demonstration of the value of basic engineering training in the solution of large social and economic problems." He has been associated with Kansas State College in educational and administrative work since 1904, with the exception of three short leaves. He has been an active member of the SPEE and has served as its representative on the governing board of the Engineering Council for Professional Development since 1937.

NRC Insulation Conference Plans Held in Abeyance

No plans for the annual meeting of the Conference on Electrical Insulation of the National Research Council are being made for the immediate future, according to a recent announcement by W. F. Davidson, chairman of the NRC division of engineering and industrial research. It is possible, however, that the committee on physics or the committee on chemistry may schedule some meetings with the conventions of the American Physical Society and the American Chemical Society.

Future Meetings of Other Societies

American Chemical Society. National Chemical Exposition and National Industrial Chemical Conference, November 17–21, 1942, Chicago, Ill.

American Institute of Chemical Engineers. 35th annual meeting, November 16–18, 1942, Cincinnati, Ohio.

American Institute of Mining and Metallurgical Engineers. Regional meeting, October 12–17, 1942, Los Angeles, Calif.

American Physical Society. 251st meeting, November 27–28, 1942, Chicago, Ill.

American Society of Mechanical Engineers. Fall meeting, October 12–14, 1942, Rochester, N. Y.; annual meeting, November 30–December 4, 1942, New York, N. Y.

American Society of Tool Engineers. Semiannual meeting, October 16–17, 1942, Springfield, Mass.

American Welding Society. 23d annual meeting, October 12–15, 1942, Detroit, Mich.

Electrochemical Society. Fall meeting, October 7–10, 1942, Detroit, Mich.

National Electrical Manufacturers Association. Annual meeting, October 26–30, 1942, New York, N. Y.

National Safety Council. 31st national safety congress and exposition, October 27–29, 1942, Chicago, Ill.

Pacific Coast Electrical Association. Bus development and administrative sections, October 22–3, 1942, Fresno, Calif.

LETTERS TO THE EDITOR

INSTITUTE members and subscribers are invited to contribute to these columns expressions of opinion dealing with published articles, technical papers, or other subjects of general professional interest. While endeavoring to publish as many letters as possible, Electrical Engineering reserves the right to publish them in whole or in part or to reject them entirely. Statements in letters are expressly understood to be made by the writers. Publication here in no wise constitutes endorsement or recognition by the AIEE. All letters submitted for publication should be typewritten, double-spaced, not carbon copies. Any illustrations should be submitted in duplicate, one copy an inked drawing without letter, the other lettered. Captions should be supplied for all illustrations.

Cover Photograph

To the Editor:

That transmission lines of the Pacific Northwest have their lightning troubles is emphasized in the accompanying photograph [reproduced on the cover of this issue]. This picture was taken in early July, 1942, near the Bonneville-Grand Coulee 230-kv lines. The storm was traveling toward the point of observation, the farthest stroke having occurred a few seconds before the near one. Heavy rain fell in the vicinity of the near stroke and is discernible in the light rays emanating from the cloud. Both strokes occurred some distance behind the lines as is evident from the silhouetted towers. The peculiar appearance of the near stroke passing through the tower, and between the observer and the lines of the near circuit, is due to film halation. No outages occurred from these strokes. The photograph contains some points of interest. In particular, it indicates that the near stroke contains a multiplicity of streamers, while there are only two partially discernible in the farther one. The fact that lightning strokes may or may not contain branching has been commented upon in various publications. But aside from showing that the difference is not a function of polarity, the phenomenon has not been very well explained. It would seem that if we can formulate a reasonable explanation for branching or for not branching, we may have a more definite clue to the formation and nature of lightning charges. The observations which follow are submitted as possible clues, with the hope that other contribu-

tions may lead to an ultimate understanding of the phenomena.

If the mechanism of atmospheric charges can be likened to static electricity as we know it on a smaller scale, we can assume that (for discharges to earth) the cloud and earth form electrodes about a dielectric field wherein the energy is stored prior to discharge. The cloud is not comparable to a metallic electrode, and some investigators believe that different parts of the cloud are charged to opposite polarities, which must presuppose that the cloud acts as a dielectric medium within itself as well as an electrode for the discharge to ground. If the energy storage prior to a discharge is in the dielectric medium between the electrodes, as we would normally suppose, the formation of streamers due to breakdown within the dielectric is not difficult to understand. But if the reasoning which makes streamers understandable is applied to lightning phenomena in general, it is difficult to explain the strokes without streamers, or those with only occasional streamers, which from visual observations are probably the most common.

There is a difference between natural and laboratory lightning that may be comparable. In the laboratory, the energy storage is in a dielectric medium that does not break down at flashover. The arc takes place between electrodes that are apart from the capacitors wherein the charge is stored. Usually, photographs of these discharges have no branching, although frequently additional streamers emanate from the electrodes, and occasionally the arcs contain loops.

Branching in both directions is shown in a laboratory discharge ("Lightning—Progress in Lightning Research in the Field and in the Laboratory," by F. W. Peek, Jr., AIEE *Transactions*, volume 48, 1929, pages 436–48) made with glass-plate *capacitors* charged without rectifiers from an alternating-current source. This discharge occurred in an area that may have been within a charged field prior to flashover.

High-frequency oscillator (Tesla coil) discharges contain a multiplicity of branches, or at least they appear so. They also emanate from a single electrode and do not necessarily terminate on another electrode. This discharge is oscillatory, and therefore both polarities are involved in the phenomenon.

H. L. RORDEN (M'36)
(Bonneville Power Administration, Portland, Oreg.)

Balancing Three-Phase Water-Rheostat Loads

To the Editor:

Much difficulty is usually encountered in endeavoring to balance three-phase water-rheostat loads during student laboratory experiments. However, there is a very systematic method of achieving a three-phase balance without approximations. The procedure is direct and simple. A thorough search in handbooks and textbooks on laboratory procedure and an inquiry among the faculty at the California Institute of Technology, seem to indicate, however, that this system is not generally known.

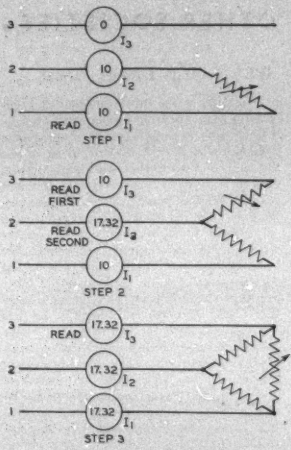

Figure 1. Method of balancing three-phase water rheostats

Step 1—Adjust load between lines 1 and 2 till meter reads 10 amperes

Step 2—Adjust load between lines 2 and 3 till $I_2 = I_1$. Read I_2

Step 3—Adjust load between lines 3 and 1 till $I_3 = I_2$. Load is then balanced

The method is best illustrated by a numerical example. If we want a balanced three-phase load of 17.32 amperes per line, then, referring to the accompanying diagram, have all rheostats completely out, and:

Step 1. Cut in water rheostat between lines 1 and 2 until the ammeter in line 1 reads $17.32/\sqrt{3}$ or 10 amperes. The ammeter in line 2 then also reads 10 amperes.

Step 2. Cut in water rheostat between lines 2 and 3 until the ammeter in line 3 reads 10 amperes. The current in line 1 is unaltered, and line 2 now carries $10\sqrt{3}$ or 17.32 amperes.

Step 3. Cut in water rheostat between lines 1 and 3 until the ammeter in line 3 reads 17.32 amperes. The current in line 2 is not altered by this adjustment, because of the previous balance existing between lines 1–2 and 2–3. Line 1 now reads 17.32 amperes, and the load is completely balanced.

Recapitulating, to get a balanced load of I amperes with no load on originally, put $I/\sqrt{3}$ amperes onto lines 1 and 2. Then, adjust the load between lines 2 and 3 until $I/\sqrt{3}$ flows in line 3. Adjusting the load between lines 1 and 3 until I amperes flows in line 3 then produces the balanced three-phase load desired.

If a dynamometer board is utilized, so that one ammeter is used for all three currents, no complication is introduced, and, furthermore, extreme accuracy in balancing is obtainable.

It is to be emphasized that all load must be off the lines before the balancing process is started. To increase or decrease the balanced load, it is a simple matter to start all over again; if this is not desired, proceeding in the same systematic manner will produce a different balanced load; that is, altering the load between lines 1–2, then altering load 2–3 till $I_3 = I_1$, and finally adjusting load 3–1 till $I_3 = I_2$. This method is just as applicable to nonunity-power-factor loads.

In case accidental unbalance occurs, it is best to start all over again.

If metal resistor banks are available for loads, this method is not needed. However, as much as one hour of a three-hour experiment has been saved when using this systematic method, rather than the usual hit-or-miss procedure, for balancing water rheostats.

VICTOR WOUK
(Research Laboratories, Westinghouse Electric and Manufacturing Company, Pittsburgh, Pa.)

Two Network Theorems

To the Editor:

In the April 1942 issue of *Electrical Engineering*, Henry Ling demonstrates two network theorems (Letter to the Editor, pages 225–7). Both of these are special cases of a more general network theorem discussed by me in the *Proceedings* of the Institute of Radio Engineers, volume 28, September 1940.

Refer to Figure 1. The impedances $Z_1, Z_2, \ldots Z_n$ terminate in a common junction 0′. The opposite ends of these impedances are numbered $1, 2 \ldots n$, whereas 0 is any other point in the network. In the article referred to it is demonstrated that

$$V_{00'} = \frac{\sum_{s=1}^{n} V_{0s} Y_s}{\sum_{s=1}^{n} Y_s} \qquad (1)$$

where $V_{00'}$ is the voltage drop from 0 to 0′, V_{0s} is the voltage drop from 0 to s and $Y_s = 1/Z_s$ is the admittance corresponding to the sth impedance.

If between 0 and the kth impedance there

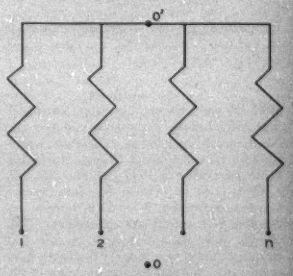

Figure 1

is a generator whose voltage drop is V_{0k} whereas the terminals 1, 2 . . . n (except k) are directly connected to 0, then equation 1 becomes

$$V_{00'} = \frac{V_{0k} Y_k}{\sum_{s=1}^{n} Y_s} \qquad (2)$$

This is Ling's first theorem.

In the more general case (with none of the voltages V_{0s} equal to zero) then the current in the kth branch is

$$I_{0'k} = \frac{V_{0'k}}{Z_k} = Y_k(V_{0'0} + V_{0k}) = Y_k(V_{0k} - V_{00'})$$

or

$$I_{0'k} = Y_k V_{0k} - Y_k \frac{\Sigma V_{0s} Y_s}{\Sigma Y_s} \qquad (3)$$

where use was made of equation 1. This is Ling's second theorem. The notation used here differs from that used by Ling, who introduces a "dropping factor" defined by

$$D_k = \frac{Z}{Z_k} = \frac{1}{Z_k Y} = \frac{Y_k}{\sum_{s=1}^{n} Y_s} \qquad (4)$$

and "the short-circuit current of the source" in the kth branch as

$$I_k = \frac{V_{0k}}{Z_k} = V_{0k} Y_k \qquad (5)$$

Using equations 4 and 5, the results 2 and 3 may be written as

$$V_{00'} = D_k V_{0k} \qquad (6)$$

and

$$I_{0'k} = I_k - D_k \sum_{s=1}^{n} I_s \qquad (7)$$

Equations 6 and 7 are forms used by Ling.

JACOB MILLMAN (A'37)

(Assistant professor of electrical engineering, The College of the City of New York, now on leave of absence as research associate at the Radiation Laboratory of Massachusetts Institute of Technology, Cambridge)

A Peace Worth Fighting For

To the Editor:

President William E. Wickenden's address on "A Peace Worth Fighting For" (*EE, Mar. '42, p. 113–19*) and the comments upon it in Professor C. M. Jansky's letter published on pages 386–7 of the July 1942 issue of *Electrical Engineering* are most illuminating.

We can all agree to the statement that the only solution to the problem of German revolt against the world, is the transformation of the German outlook on all the essential questions that have faced humanity for so many centuries.

While undoubtedly there has been a recrudescence of German militarism in the last 80 years, the German people and their predecessors the Huns, have been militaristic for about 2,000 years, or perhaps longer. Is it not worthwhile to try to discover the reason for the reappearance of this militarism 80 years ago?

The date coincides almost exactly with the publication in 1859 of Darwin's "The Origin of Species." It is a strange thing to say but I am convinced that Darwin, one of the greatest scientists the world has ever known, is largely to blame for this destructive attitude of the German people.

Since the beginning of what we call Western civilization and particularly since the beginning of Christianity, the masses have had their religion, to curb their passions, limit their injustices, control their greed, lust, and anger—the primary causes of war. With the publication and development of the Darwinian theory with its insistence on the natural evolution of man and its discard of the Biblical story of creation, and with the gradual seepage of the theory of evolution and particularly of the survival of the fittest through the greater part of the masses (and the Germans have understood the survival of the fittest as the survival of the strongest) the power of religion has been weakened, that is, of religion as generally understood. This, of course, is an entirely erroneous understanding of Darwin, and of the many others that have advanced the study of evolution, including Bergson and his "Creative Evolution." Up to the present, really nothing has arisen to take the place, in the hearts of the great masses, of the hold that Christianity, whether Protestant or Roman Catholic, Judaism, and the other religions had. Some attempts have been made by the "Ethical Culture" societies founded by Felix Adler, the advanced Unitarian, and the Humanist movement; but none of these has been able to make any important headway against the old established religions.

What I mean to say is that until we are able to get some popular religion that will catch the hearts of the masses and which they can understand and cling to, or to put it in another way, until the differences between science and religion disappear and the people understand that it is not necessary to believe in a hereafter or in resurrection, to be good, progress along ethical lines will be difficult.

To connect this with the present problem of the German revolt and the problem of what to do when victory comes to the democracies, as it must come, seems to lead to the conclusion that the only way to control German militarism is to leave an army of occupation in Germany for at least three generations, or until such time as the democratic nations are fully convinced that the Germans, and especially the German youth, have become religious enough to be trusted to follow the principles of the Sermon on the Mount and to have faith in the high destiny of humanity, when greed, lust, and cruelty will have disappeared or become less prevalent, and the world will be ruled mainly by honesty, justice, benevolence, and magnanimity.

It is true that a great many of the rest of us have not yet reached that desirable condition, but at least we have discarded inordinate cruelty, mass murder, and incredible treachery in the relations between governments, even if in our relations with each other the principles of greed, selfishness, and cruelty still rule pretty well all over. At least let us be sure that governments, in their relations with each other, will reach some degree of fair dealing and of understanding of the sanctity of international agreement.

G. LOBO (F'12)

(President and treasurer, Kelvin Engineering Company, New York, N. Y.)

A Suggestion for Saving Power

To the Editor:

The technical press, many of the newspapers, and all of the government officials vitally concerned are stressing the fact that there is an impending power shortage in the United States. The solution proposed is the installation of additional generating capacity either through public finances or by means of private capital.

It is believed, however, that there are ways and means of increasing the supply of power by decreasing losses on transmission and distribution circuits. It is a natural thing for losses to take place on electrical circuits, but it is absolutely unnatural and abnormal where the losses equal or exceed 40 per cent of the power that is usefully employed. We have such a situation existing in series street lighting circuits today.

A rate case was recently completed before the New York Public Service Commission which involved the reasonableness of the street lighting rates in the Village of Roslyn in Nassau County, Long Island, N. Y. Current in this area is supplied by the Long Island Lighting Company. During the course of the hearings one of the company experts revealed the fact that 44 per cent of the total energy generated for street lighting purposes in the territory of the company is lost, wasted, or otherwise unaccounted for. This dreadful inefficiency exists only in series circuits.

The series street lighting circuit today is a direct descendant or relic of case 10,388—Roslyn versus the Long Island Lighting Company—and the original lighting system of the early days when streets and roads were illuminated with carbon-arc lights which were almost invariably connected in a series circuit. When incandescent lamps gradually replaced the carbon-arc lamp it seemed desirable to retain as much of the original equipment as possible. As a result we have the present highly inefficient series street lighting circuits in use today. To add to the unnatural condition, the cost of a series street lighting transformer is more than that of the ordinary distribution transformer. Based on figures developed during the hearing, it was shown that a series street lighting circuit required an investment of $96 per kw for transformer capacity as compared with a cost of $12.20 per kw if a multiple system was substituted. The reliability of the series circuit is, of course, considerably less than the reliability of an average multiple circuit. In

the case of a wire breakage in a series circuit, the entire circuit is put out of use. A broken wire in the multiple circuit merely affects the lamp or lamps that are on that particular portion of the circuit.

Losses in multiple circuits hardly ever exceed 15 per cent to 18 per cent and it would seem incumbent upon the electrical industry, both the manufacturers and the utilities, that considerable thought be given to this situation of extremely high losses on series street lighting circuits in use today. In some isolated instances multiple street light circuits are in use, but these constitute a relatively small percentage.

If electric power is to be rationed, it would seem desirable to put at the top of the list, series street lighting ahead of all other classes of usage.

L. MACKLER (M'24)

(Consulting engineer, New York, N. Y.)

Editor's note: Under wartime shortages of critical materials, power loss and voltage regulation commonly are condoned to conserve materials.

NEW BOOKS • • •

The following new books are among those recently received at the Engineering Societies Library. Unless otherwise specified, books listed have been presented by the publishers. The Institute assumes no responsibility for statements made in the following summaries, information for which is taken from the prefaces of the books in question.

These and thousands of other technical books may be borrowed from the library by mail by AIEE members.

All inquiries related to purchase of all books reviewed in these columns should be addressed to the publisher of the book in question.

Report Writing. By C. G. Gaum, H. F. Graves, and L. S. S. Hoffman. Revised edition. Prentice-Hall, New York, 1942. 332 pages, diagrams, etc., 9½ by 6 inches, cloth, $2.75.

A presentation of certain principles of composition and rhetoric pertaining to the special field of the report, intended for use as a college text and for independent study. No fundamental changes have been made in the new edition, but the illustrative material, specimen outlines, and reports have been replaced by recent items; the rules for abbreviations have been changed to standard ones; and a section on letters of application has been added.

What the Citizen Should Know About Civilian Defense. By W. D. Binger and H. H. Railey. W. W. Norton and Company, New York, 1942. 183 pages, diagrams, etc., 8½ by 5½ inches, cloth, $2.50.

This book presents the advice of an experienced civil engineer and a writer upon military affairs as to proper methods of dealing with the civil problems arising out of enemy air action. The various types of bombs are described, and instructions as to protection against them given. Construction of shelters, preparation for blackouts, fire control, and gas are discussed.

Introduction to Control Engineering. By E. S. Smith. Apply to author, 114–57 176th Street, St. Albans, N. Y., 1942. Paged in sections, diagrams, etc., 11 by 8 inches, paper, including separate pamphlet of figures, $2.

These notes represent lectures on control and its applications in the process industries given by the author for an engineering, science, management, and defense-training course at Pratt Institute. The book is intended for those actively working with industrial measuring and controlling instruments and is intended as an introduction to the basic principles that underlie the solution of specific problems.

Analytic Geometry. By C. H. Lehmann. John Wiley and Sons, New York, 1942. 425 pages, diagrams, etc., 9 by 6 inches, cloth, $3.75.

A textbook for a first course in plane and solid analytic geometry. Special features are the completeness of the investigations of each topic, the construction of tables summarizing closely related results, a fuller treatment of solid analytic geometry than is usual in elementary texts, and the large number of exercises included.

The Lineman's Handbook. By E. B. Kurtz. Second edition. McGraw-Hill Book Company, New York and London, 1942. 650 pages, illustrations, etc., 7½ by 5 inches, $4.

A presentation of procedure and methods of line construction, accompanied by an introductory explanation of electrical principles and electric systems. The new edition has been thoroughly revised, and new chapters have been added on rural lines, tower-line erection, pole-top resuscitation, safety and rural-line operation, and maintenance.

Industrial Camouflage Manual. By K. F. Wittmann. Reinhold Publishing Corporation, New York, 1942. 128 pages, illustrations, etc., 11 by 8½ inches, paper, $4.

Presents experiments and experiences developed in the classrooms and camouflage laboratory of Pratt Institute. The presentation is largely by drawings and photographs. Principles, methods, and materials are described and demonstrated on models and by actual installations.

Your Career in Engineering. By N. V. Carlisle. E. P. Dutton and Company, New York, 1942. 253 pages, illustrations, etc., 8½ by 5½ inches, cloth, $2.50.

The aim of this book is to give young readers aid in choosing a vocation. The author describes the major divisions of engineering and some of the important special fields, telling what each accomplishes, how it works, and the opportunity it affords. Advice as to education and training is also included.

Principles of Radio. By K. Henney. Fourth edition. John Wiley and Sons, New York; Chapman and Hall, London, 1942. 549 pages, illustrations, etc., 8 by 5 inches, cloth, $3.50.

Aims to present the principles of radio in a form adapted to students with little electrical or mathematical background. The book is intended primarily for trade schools and for self-instruction. This edition has been revised and brought up to date.

Calculus for Practical Engineers. By A. Cibulka. Distributors, Hemphill's Book Store, Austin, Texas, 1942. 100 pages, diagrams, etc., 12 by 9 inches, paper, $3.

A concise presentation of the fundamentals of differential and integral calculus, illustrated by numerous practical examples.

PAMPHLETS • • •

The following recently issued pamphlets may be of interest to readers of "Electrical Engineering." All inquiries should be addressed to the issuers.

Service Equipment Standards. National Electrical Manufacturers Association, New York, N. Y., 1942. 18 pages, 30 cents.

Learning the Radio Telegraph Code. American Radio Relay League, West Hartford, Conn., 1942. 34 pages, 25 cents.

The Role of the Housebuilding Industry. By Miles L. Colean. National Resources Planning Board, Washington, D. C., 1942. 29 pages.

Priorities and Industry. Division of Information, War Production Board, Washington, D. C., 1942. 83 pages.

Recommended Practice of Office Lighting. Committee on Lighting Practice, Illuminating Engineering Society, New York, N. Y., 1942. 47 pages, 25 cents.

Labor Arbitration in Wartime. The American Arbitration Association, New York, N. Y., 1942. No cost.

A Table of Common Hazardous Chemicals. The National Fire Protection Association, Boston, Mass., 1942. 20 cents.

Papers Presented at the Sixth Short Course in Coal Utilization (Engineering Experiment Station circular series No. 43). University of Illinois, Urbana, 1942. 112 pages, 50 cents.

Code of Minimum Requirements for Instruction of Welding Operators (Part A—Arc Welding of Steel 3/16 to 3/4 Inch Thick). American Welding Society, New York, N. Y., 1942. 68 pages, 50 cents.

Typical Residential Electric Bills for the Middle Atlantic States: New Jersey, New York, and Pennsylvania. Federal Power Commission, Washington, D. C., 1942. 60 pages, 25 cents.

TRANSACTIONS SECTION

Preprint of Corresponding Pages From the Current Annual AIEE Transactions Volume

Any discussion of these papers will appear in the December 1942 Supplement to Electrical Engineering—Transactions Section

Motor Insulation, Heat, and Moisture

P. H. McAULEY
ASSOCIATE AIEE

Insulation Tests

THE subject of nondestructive tests on insulation has received much attention. Since a function of insulation in a given application is to provide a certain minimum dielectric strength, tests at their greatest usefulness would give a measure of dielectric strength without requiring a dielectric breakdown. Additional indications like proneness to loss of dielectric strength if subjected to certain hazards of service are valuable, and information on the deterioration or aging of insulation with service may follow from periodic tests.

Current Practices

Although an ideal test has yet to be devised, the insulation resistance and power-factor methods are widely used for nondestructive tests on insulation. Insulation-resistance measurements are recognized in many test codes and standards.[1,2] A formula is given for the insulation resistance to be expected in a clean dry machine at 75 degrees centigrade. In some cases the same formula is given for a minimum safe value. In 1934 Wieseman[3] pointed out inadequacies of this formula and suggested improvements, and his work seems to deserve more recognition. Dielectric absorption has appreciable influence upon indicated values of insulation resistance but is not mentioned in recent standards like the Test Code for Single-Phase Motors, November 1941. This absorption effect is appreciable and may be taken into account by establishing a definite time of voltage application for making observations. Actually, many of the deductions made by an experienced Megger operator are hard to formulate or standardize.

Capacitance and power-factor measurements have proved valuable for field testing of high-voltage insulation as in bushings or transformers. These measurements are largely detectors of moisture in sealed or oil-insulated types of apparatus.[4,5] For rotating apparatus perfect sealing is difficult, and a varnish film protects the insulation. Appreciable moisture can be tolerated, at least to the extent that power-factor measurements seem less significant.

An extensive and prolonged study of nondestructive tests leading to many improvements in technique has been conducted on very large machines by an Edison Electric Institute committee.[6] Field tests provide convincing evidence of any conclusions or limits established. Laboratory investigations however permit accelerated tests with one variable under study at a time, and dielectric strength tests leading to correlation with the nondestructive indicators are possible. In the belief that a study of testing methods under extreme conditions might prove helpful in interpreting field data and permit suggesting limits based on dielectric strength, some motors of the five-horsepower 440-volt class or smaller have been subjected to severe temperature or moisture conditions.

Laboratory Tests

Two similar five-horsepower three-phase 220–440-volt induction motors have been operated more than two years on an overload cycle. Each working day one motor has been brought to a temperature of 125 degrees centigrade by winding resistance, the other to 100 degrees centigrade. Insulation resistances have been observed before starting and immediately after shutdown each day. The motors have been started across the 230-volt line with 15-kw d-c generators connected. Operation thus has been similar to actual service conditions with one unit delivering about 7.2 horsepower and the other 6.4 horsepower.

Several fractional-horsepower motors have been subjected to high humidity conditions. After several trials with various cooling cycles by refrigeration, the simple arrangement of exposing the samples at room temperature in a closed metal chamber with water in the bottom (appendix I) was adopted. Insulation resistances, dissipation factors* and capacitances on samples so conditioned have been recorded periodically. Dielectric breakdown tests have been made on a number of the samples.

Motors are not suitable samples on which to secure extensive data on dielectric breakdown voltages. Accordingly, small wax-dipped paper-insulated capacitors, which could be conditioned readily, have been used to observe the relation between dielectric strength, insulation resistance, and dissipation factor under exposure to high humidity.

Insulation-Resistance Measurements

Careful technique and analysis show promise of increasing the significance of insulation-resistance measurements. The following considerations should be given attention:

(*a*). The influence of external leads should be eliminated.

(*b*). The effect of time of voltage application should be taken into account by making observations at a definite time such as one minute after test voltage is applied, or by exploring the dielectric-absorption curve.

(*c*). A definite trend in insulation resistance for weeks or months may be of significance where individual values are not.

Paper 42-124, recommended by the AIEE committee on electrical machinery and standards coordinating committee 4 for presentation at the AIEE summer convention, Chicago, Ill., June 22–26, 1942. Manuscript submitted April 6, 1942; made available for printing May 13, 1942.

P. H. McAULEY is with the engineering laboratories and standards department, Westinghouse Electric and Manufacturing Company, East Pittsburgh, Pa.

The encouragement and assistance of R. E. Hellmund are gratefully acknowledged.

* Dissipation factor is the cotangent of the angle of which power factor is the cosine. It is often multiplied by 100 and given in per cent.

(*d*). Measurements at room temperature are attractive for practical reasons.

In both the high-temperature and the moisture tests on motors, leads influenced resistance readings. About ten feet of rubber-insulated cable lying on a wooden floor was connected to each of the five-horsepower motors. The cables were isolated and checked for insulation resistance at the start of the test which happened to be in the winter time. Later it was found, under summer humidity conditions, that the cable resistances were less than those of the motors. Similarly, on the small motors subjected to high humidity, leakage between the leads and frame in the terminal boxes determined observed insulation-resistance values at times. Hence, an essential precaution to obtaining significant values on motor

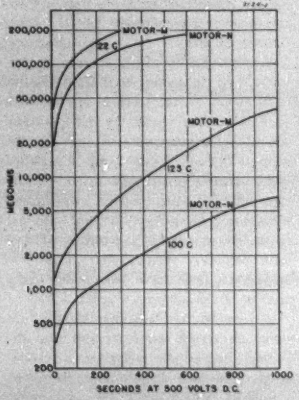

Figure 1. Insulation resistances hot and at room temperature on two five-horsepower motors on daily load cycle

insulation is to make sure that leads[7] are not influencing the results.

The effect of time of voltage application is shown in Figure 1 which gives insulation resistance values before and after one of the daily runs for each of the five-horsepower motors. For the curves while hot, the machines were cooling rapidly from the high temperatures of operation. Thus, cooling as well as dielectric absorption contributed to the increase of apparent insulation resistance with time. The 125 degrees centigrade motor, for instance, in 15 minutes has reached a resistance higher than the five-second value at room temperature. Times longer than 15 minutes appear necessary to arrive at steady-state conditions. These are not practical for small apparatus, but the rapid changes with time indicate the desirability of selecting a definite time arbitrarily for comparative values. For data in this paper insulation resistance values are for one minute after application of 500 volts d-c. Bridges with electronic balance indicators were used.

An enclosed d-c motor operated daily at 165 degrees centigrade has shown a reversal of the trend of change in insulation resistance. With the test started in August, the hot insulation resistance of the armature increased gradually from 2.2 to 1,000 megohms with drying and curing of the insulation. However, after several months operation enclosed and overloaded, the effect of brush dust reversed this trend. It was even more apparent in room-temperature-resistance values. In one case, these dropped from 7,500 megohms to 50 megohms over a period of six months. Simply cleaning the armature with compressed air raised the resistance to 30,000 megohms.

Electrical standards usually suggest a temperature of 75 degrees centigrade for insulation-resistance measurements. This temperature tends to minimize the effects of moisture, but a machine may require many hours or days at 75 degrees centigrade to reach a steady state of insulation resistance. On large generators the pertinent question often is whether continued operation is safe. On small machines the information may be required to determine the advisability of applying voltage and starting operation without drying. Therefore, the usefulness of tests would be enhanced by making measurements and establishing limits for a temperature in the ambient range.

Aging of Insulation

The temperature aging of insulation is difficult to detect from insulation-resistance measurements. It does not seem possible to draw conclusions on the relative insulation condition of the motors operated at 125 degrees centigrade and 100 degrees centigrade, although further experience may disclose significant relations. A physical examination shows that the 125 degrees centigrade insulation is somewhat brittle. Probably, it would be much more vulnerable to long or severe exposure to vibration or moisture. But where the operating schedule is regular, standard temperature limits appear conservative for many conditions of operation. From these tests the following observations were made, applying of course to thoroughly baked insulation:

(*a*). At room temperature the induction motors clean and dry had insulation resistances of from 100 to 100,000 megohms. In summer the values were below 1,000 megohms. In winter in a heated room 10,000 to over 100,000 megohms were obtained.

(*b*). A heated motor showed insulation resistance upon cooling of 10,000 to 1,000,000 megohms or an increase of 10 to 100 times.

(*c*). The 125 degrees centigrade motor had hot resistances of 1,200 to 2,500 megohms after 18 months operation, while the 100 degrees centigrade motor varied between 500 and 1,200 megohms. These values appear to have increased with aging of the insulation, but this point is submerged by the effects of the leads in the early part of the tests. The daily changes with temperature correspond fairly well with temperature correction curves[8] given by Rylander.

(*d*). One feature in comparing results on the two motors is the relative consistency of the resistance values. The day-to-day variations seem closely related.

(Table I shows values for one week. When one motor changed up or down, the other tended to do likewise. Many exceptions occurred, but there seemed to be a definite consistent relation, which suggests the influence of external conditions affecting both motors alike. Possibly it was simply temperature variations resulting from changes in line voltage or ambient temperature. The evidence is good that certain influences were functioning consistently and, that wide variations in insulation resistance may appear more logical with a better understanding of all the variables involved.)

(*e*). During weekends or occasional longer periods of shutdown, insulation resistance values tended to fall. This suggests that the room temperature reading at any given time is influenced by the integrated effect of moisture absorption since the previous heating period. It follows that a single humidity reading at the time of a test is not likely to be significant.

Table I. Insulation Resistances in Megohms on Two Five-Horsepower Motors Following Daily Load Runs

Motor	Mon	Tues	Wed	Thurs	Fri
125 C	1,100	750	1,300	2,000	1,500
100 C	700	650	700	800	750

Moisture

Insulation is affected by exposure to moisture in spite of varnish treatments and usual methods of enclosure. These

Table A

Operating Voltage	Minimum Megohms 20 C–30 C	AIEE Formula Megohms 75 C
110	0.1	0.11
220	0.5	0.22
440	3	0.44
550	5	0.55

factors influence the rate of moisture absorption and drying. On motors standing idle, the absorption is cumulative and appears to be readily reversible.

Four 1/4-horsepower three-phase 440-volt enclosed motors were used as test samples. Measurements were made under the following conditions:

(*a*). As received from the factory.

(*b*). After five hours at 48 degrees centigrade.

(*c*). After 25 hours at 74.5 degrees centigrade.

(*d*). After 44 hours at 95 degrees centigrade.

(*e*). During 18 days standing at room temperature.

(*f*). After 15 hours at five degrees centigrade and seven hours at room temperature.

These test conditions were consecutive and represent a drying cycle, an idle period, and a cooling cycle conducive to condensation. Figure 2 gives capacitances and dissipation factors observed with a 115-volt 60-cycle bridge for conditions (*a*) to (*e*) inclusive on one motor, and the others were quite consistent. The record of moisture absorption is definite. The 30 per cent dissipation factor at the start and the decrease in capacitance and dissipation factor with drying are characteristic of moisture. The later increase in dissipation factor and capacitance when exposed to prevailing summer humidities indicates a slow but definite reabsorption of moisture. The rate varies appreciably and the trend reverses at times. In 18 days the original condition was not yet attained again.

Table II gives insulation-resistance data on the four motors for conditions (*a*) to (*f*) except that only one set of values was recorded during the 18-day idle period. The consistency in performance of the four motors is noteworthy. In all cases values on the different motors are of the same order of magnitude under given conditions. Columns 2, 6, and 7, however, are all for room-temperature measurements at different stages of moisture absorption. Drying increased insulation resistances about 100 times. A cooling cycle conducive to condensation later caused a 1,000 to 1 decrease. In analyzing measurements made at room temperature these variations must be recognized.

Table II. Insulation Resistance in Megohms for Four Small 440-Volt Motors at Controlled Temperatures

1 Motor	2 28 C	3 48 C 5 Hrs	4 75 C 20 Hrs	5 95 C 19 Hrs	6 22 C 23 Hrs	7 25 C (18 Days) 5 C (15 Hrs) 25 C (7 Hrs)
A	460	125	430	415	22,000	27
B	475	119	400	445	65,000	16
C	455	99	340	360	42,000	25
D	495	106	310	340	38,000	31

Accelerated test data for motor *A* without rotor or end bells in the 100 per cent humidity test chamber are given in Table III. After a few days dissipation factor and capacitance increased to the point where readings could not be obtained. The insulation resistance decreased steadily with time of exposure to well below one megohm, and the process seems to be an extension of the rate and the degree observed at ambient humidity.

A number of used motors which had been in storage for years were tested. The dissipation factors were between 30 and 45 per cent. Motor insulation appears to absorb moisture to this extent under normal conditions of storage in summer, and this effect has been observed on idle generators.[6] New and used motors do not appear greatly different unless in the time element involved following a drying treatment.

Further moisture-exposure tests were made on the four motors after redrying. Figure 3 shows the insulation-resistance data.

Curve *A*—Stator only as in Table III.

Cuve *B*—Retreated stator with a different varnish.

Curve *C*—Same as *A*, but enclosed and with synthetic tubing leads to eliminate lead leakage.

Curve *D*—Retreated stator with a different varnish immediately after drying.

The motors were exposed at high humidity for 71 days, and insulation resistances decreased steadily and consistently. Dissipation factors also indicated similar absorption with time, but readings were less consistent in the later stages of the test.

Curve *A*, Figure 3, duplicates the similar test of Table III rather well. By comparison, *C* shows that enclosure retarded absorption materially. Better varnish treatment in cases *B* and *D* did likewise and this result agrees with statistical service data. Improved results have been obtained under some service conditions with additional and special varnishes. These protective measures influence the insulation state reached in a given time.

For part of the test, a voltage of 115 and later 230 volts, 60-cycle, was applied between the windings and iron of stator *A*, Figure 3. When this voltage was removed, the insulation resistance dropped from a 0.4-megohm level to 0.08 megohm. No improvement occurred on application of the voltage, but further depreciation was prevented. The evidence is meager, but further study of

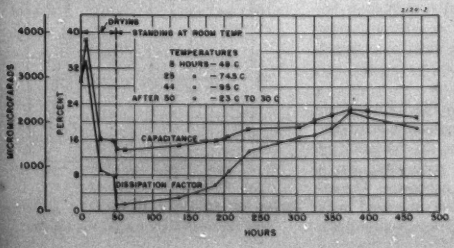

Figure 2. Effect of drying and exposure at summer humidity conditions on capacitance and dissipation factor of small motor insulation

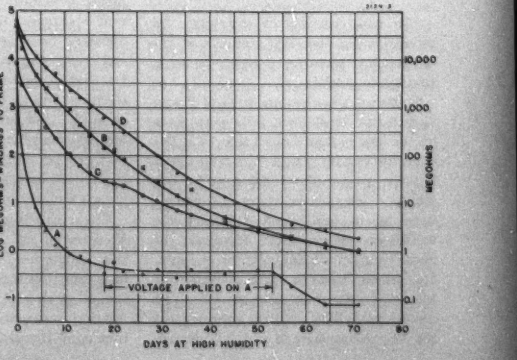

Figure 3 (right). Insulation resistances of small motors in humidity-conditioning chamber

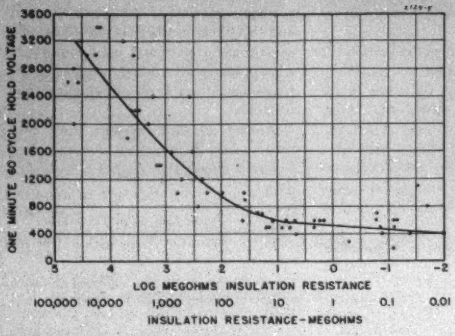

Figure 4. Relation between dielectric strength and insulation resistance on capacitors in moisture-exposure tests

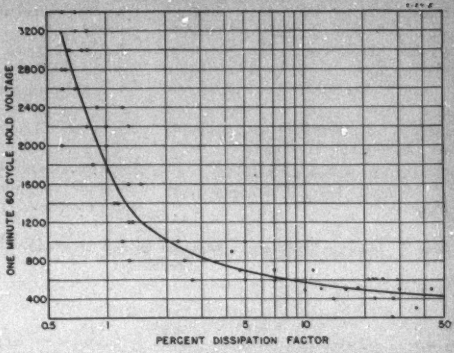

Figure 5. Relation between dielectric strength and dissipation factor on capacitors in moisture-exposure tests

the value of keeping some voltage on insulation to ground under adverse moisture conditions seems warranted. Unfortunately, this measure is not readily applicable to intercoil insulation.

The process of moisture absorption appears to be reversible. If the insulation is dried or even stored in a heated room, recovery is appreciable and rather rapid. The motors were dried between the tests of Table III and Figure 3 apparently without affecting later performance. Table IV gives readings on the stators three days after completion of the tests of Figure 3. Insulation resistances and dissipation factors, in spite of dielectric breakdown tests in the meantime, indicate appreciable drying has occurred at room temperature. The rate depends again upon the varnish treatment. The problem resolves into avoiding the application of voltage when the insulation is in a weakened condition.

Dielectric Strength

The real criterion of suitability for service is the dielectric strength of the insulation. Moisture reduces dielectric strength appreciably.

Following the exposure tests of Figure 3, dielectric breakdown tests were made on the four motors as in Table IV. The dielectric test for new motors of this class is twice normal plus 1,000 volts for one minute. Two of the stators, *A* and *C*, were below this value following the moisture exposure tests. However, the poorer one held 1,000 volts for one minute, which leaves a little margin over operating voltage in spite of severe test conditions. The motors operated at 100 degrees centigrade and 125 degrees centigrade for two years stood a 2,000-volt momentary test after each year of operation.

Maximum 60-cycle test voltages held for one minute between motor windings and frame for different values of insulation resistance are given in Figure 7. The points at or above 4,000 volts are for new stators, and other points are following different times of exposure to moisture. The curve is drawn near the lower limit of the points. Since the points are the highest voltages held for one minute, and failures occurred at the next highest 200-volt step, the curve is of the nature of a minimum breakdown voltage curve, although a larger number of tests probably would modify it some. There is a fairly definite relation between insulation resistance and dielectric strength for these fractional-horsepower motors.

The capacitors used for dielectric breakdown tests have three layers of about 0.0005-inch paper insulation and are rated at 220 volts alternating current. Operating volts per mil are much higher than in motors, and very little moisture can be tolerated. Samples were exposed at high humidity, and a few were removed periodically and tested for insulation resistance, dissipation factor, and dielectric breakdown strength, as shown in Figures 4 and 5. There seems to be reasonably good correlation between the electrical test values and dielectric strength. For insulation resistances below 100 megohms or dissipation factors over two per cent, the dielectric strength is reduced appreciably to rapidly approach a minimum value.

These capacitors also illustrate another phenomenon on the insulation-resistance test. Figure 6 shows the variation of insulation resistance with time for a sample after 24 days exposure. The insulation resistance first increased with time as in the usual dielectric-absorption curve. After about 20 seconds the trend reversed, and after 40 seconds insulation resistance decreased rapidly with time, possibly because of a partial breakdown at 500 volts direct current. Recovery was rapid and fairly complete, however, as the sample immediately afterwards held 600 volts 60-cycle for one minute and failed at 700 volts. The same action has been observed on motors after appreciable exposure. Davis and Leftwich[8] have reported the decreasing resistance section of the curve due to defective auxiliary apparatus on generators. These effects accent the desirability of observing insulation resistance at one minute or more after voltage is applied. A 10- or 15-second Megger reading would not have disclosed the situation. Also, in this

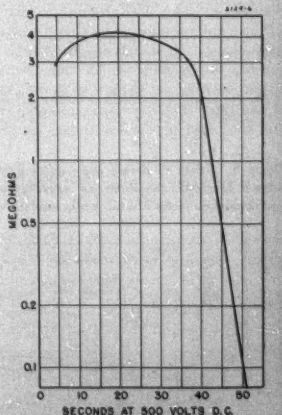

Figure 6. Insulation resistance on capacitor after considerable exposure to moisture

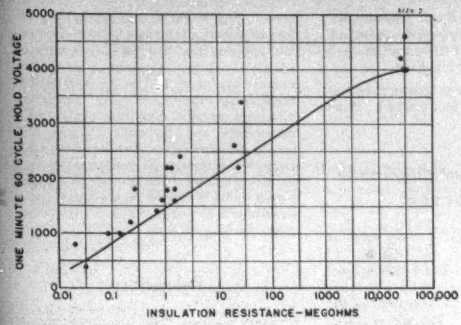

Figure 7. Relation between dielectric strength and insulation resistance for fractional-horsepower 110- to 440-volt motors

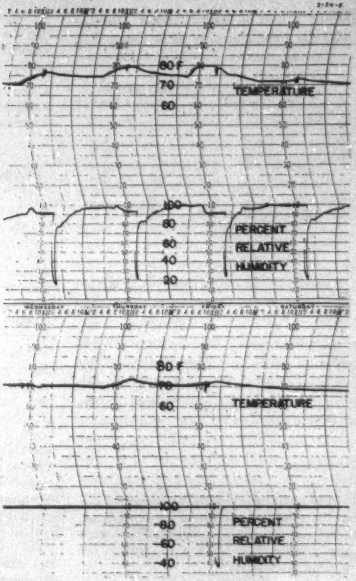

Figure 8 (right). Temperature and humidity chart from metal test chamber with water in the bottom

case at least, a weakened condition of the insulation was detected at a d-c voltage of one-half the 60-cycle crest breakdown value. These capacitor samples are small, however, and results may have been affected by heating or drying at test voltages.

Nondestructive Tests Versus Dielectric Strength

The purpose of these investigations is, of course, to determine if nondestructive insulation tests can be relied upon to indicate the suitability of apparatus for service.

1. There is some possibility of establishing for some devices minimum insulation-resistance values which will assure satisfactory operation in spite of appreciable moisture absorption.

2. The test methods studied do not appear dependable for revealing insulation defects other than moisture absorption, with the possible exception of dirt.

To establish satisfactory limits for motors considerable dielectric-strength data and field experience should be available. Table IV and Figure 7 indicate, however, that insulation strength decreases with insulation resistance. This is recognized in the standards formula for expected values at 75 degrees centigrade. However, the 75 degrees centigrade temperature implies some drying. Also, no time of voltage application is specified, which leaves to chance the inclusion of such effects as in Figure 6. Recognizing the greater usefulness of tests at room temperature, it may be reasonable to suggest from Figure 7 the following tentative limits above which small motors can be safely connected to the line for starting. The values in column 2 are for room temperature at one minute after the d-c test voltage is applied. A ratio of about 60 has been given[8] for values taken at 25 degrees centigrade and 75 degrees centigrade.

These limits allow some margin of safety at operating voltages, but wide variations in practice are to be expected. Appreciably lower values may not prove fatal in many cases. Also, where moisture is not involved, these limits may give no assurance of a satisfactory condition. In fact much higher values often may be associated with poor insulation. Additional experience on many sizes, types, and makes of motors under service conditions will be necessary for proper determination of the best values, but the possibility of establishing useful limits seems good.

The detection of defects under dry conditions is very uncertain for low-voltage apparatus. The roasted condition of the motor operated at 125 degrees centigrade was not apparent from the electrical tests. Columns 5 and 6 of Table IV also are significant. The motors had been tested to failure, but insulation resistances of 1,950, 2.1, and 3.2 megohms were later recorded for three of the windings. Motor *C* did show evidence of the previous breakdown by its zero insulation resistance. It is quite likely that higher insulation test voltages would reveal the condition in all cases. There is always danger, however, in testing at voltages much above operating voltage, or the nondestructive feature of the test may be sacrificed. The failure of insulation-resistance test voltages to disclose punctures or breaks in insulation is readily understandable. The smallest air gap will not sparkover much below 1,000 volts in short-time tests. The separation between conductor and core in small motors may be approximately 0.05 inch, and the dielectric breakdown of air for this distance usually exceeds 4,000 volts with creepage strengths somewhat lower. Consequently, if the puncture or fault is clean and reasonably dry, the insulation resistance may be affected to a small extent. The strength of the insulation between turns, coils, and phases in motors also is important. However, under

Table III. Measurements Between Windings and Frame on Stator *A* Exposed to 100 Per Cent Humidity

Days Exposed	Megohms	μμf	Per Cent Dissipation Factor
0	200,000	1,275	1.2
1	5,100	1,420	5.1
5		7,100	38
6	3.1	8,200*	> 50*
7	1.5	11,100	> 50
8	0.85	14,800	> 50
11	0.42	24,200	> 50
12	0.31	30,000	> 50
13	0.21	30,000	> 50

* These and later readings are very approximate as the bridge could not be balanced for dissipation factors greater than 50 per cent.

Table IV. Tests on Stators After 71 Days at 100 Per Cent Humidity as in Figure 4

1	2	3	4	5	6
	As Removed			After 3 Days in a Heated Room	
Motor	Megohms	Per Cent Dissipation Factor	Volts Held for 1 Minute	Megohms	Per Cent Dissipation Factor
A	0.083	> 50	1,000	1,950	17.5
B	0.88	40	1,600	2.1	31
C	1.08	> 50	2,200	0	15
D	1.95	37	2,400	3.2	34.5

service conditions, the testing of this insulation becomes rather elaborate. In a well-proportioned machine test results on the ground insulation should be indicative of general machine condition.

Conclusions

1. Test codes and standards should recognize the effect of dielectric absorption on insulation resistance and suggest a time such as one minute after voltage application for observing resistance.

2. For industrial apparatus rated below 600 volts room-temperature measurements of insulation resistance seem more practical than 75 degrees centigrade values.

3. Aging of insulation due to temperature is difficult to detect from electrical measurements. These indicators are sensitive to moisture absorption and possibly to dirt.

4. There appears to be a very good correlation between insulation resistance as affected by moisture and dielectric strength for fractional-horsepower motors.

5. Minimum room-temperature values of insulation resistance for starting small motors are suggested.

Appendix I. Humidity-Conditioning Chamber

In seeking a convenient testing cycle at high humidity, several combinations of cooling and exposure to moist atmospheres were tried. It was difficult to reproduce conditions, and considerable handling of the samples was required. The simple expedient of a closed metal can with water in the bottom finally was adopted. For most of these tests the chamber consisted of a can about 30 inches in diameter by 36 inches high with a deep lid about 34 inches in diameter. The assembly was turned upside down from the usual position, and the lid filled with water. Thus, the water provided both a seal and a source of moisture. A pinhole permitted entrapped air to escape. No temperature or humidity controls were provided other than the laboratory heating system which determined ambient conditions. Both temperature and humidity in the chamber were recorded with a Friez Hythergraph, Figure 8. These records indicate a saturated atmosphere most of the time, but this depended to a certain extent upon the condition of the samples and the frequency of opening the chamber. The time to return to maximum humidity after opening the chamber varied with ambient humidity and the duration of the open condition. Times from 0.5 to 20 hours were observed. This might be a handicap in short-time tests, but a fan should speed evaporation appreciably. For insulation tests of this kind, this type of chamber provides a simple, convenient, and easily reproducible conditioning atmosphere. The correlation to actual service conditions with wide temperature and humidity changes and moving air is problematical, but that, relatively, it is a very severe moisture-exposure test seems certain. One possible case which it does simulate closely occurs where water penetrates and remains inside an idle enclosed machine for some time.

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Ignitron Rectifiers in Industry

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WHEN a new device is developed, it is usually adopted and proved by a particular industry. In the case of the ignitron rectifier, the first applications were in transportation service in mines and railways. The apparatus and its performance in these early installations were discussed by the present authors in an earlier Institute paper.[1]

Since that time, as superior operating results became known, the ignitron has been taken up by other industries, most notably the electrochemical. In excess of 2,000,000 kw of ignitron-rectifier units have been purchased by that industry alone.

This paper will discuss primarily installations for large power concentrations.

Rectifier Description

Continuously pumped ignitrons have been applied to date in four sizes which, in six tube assemblies, have continuous ratings at 600 volts of 1,250, 1,667, 2,500, and 4,000 amperes. The 2,500-ampere size has been applied in greatest numbers. However, larger-capacity sections are desired for the larger installations, and so the majority of applications have been made using 12-tube assemblies. One design will be described.

The ignitron consists of a drawn steel tank with a removable cover plate into which is mounted the main anode bushing and anode shield terminal. Graphite continues to be the best material for rectifier anodes. The deionizing shield surrounding the anode and the baffle between anode and cathode pool, are also of graphite. This latter is insulated from the cathode to avoid the transfer of the cathode spot from cathode to baffle when high overloads are applied. The tank itself constitutes the cathode connection, since the ignitron does not require an insulated cathode and is bolted to the cathode copper bars on the assembly frame. The ignitor is mounted on a rod which passes through the side of the tank, insulated with a glass-kovar seal, on a flexible steel diaphragm. The mounting is provided with adjusting screws to enable adjustment of the ignitor from outside the tank. Solder-to-porcelain vacuum-tight seals are used for the main anode bushing. A small solid radiator terminal holds this seal within safe temperatures. The low-current potential connection to the anode shield is made through an aviation spark-plug-type bushing with a soft copper gasket. The vacuum-sealing gaskets in the separable joints of the ignitron proper, are enameled aluminum wire rings. Such gaskets operate satisfactorily at 100 degrees centigrade, and the rectifier operating temperature is objectionably close to the maximum safe temperature of rubber. However, rubber constitutes a most convenient, and semiflexible vacuum-tight gasket which requires relatively low flange pressures. Therefore, the external connections to the vacuum pumping system, which operate at low temperatures, are gasketed with iron-band-protected rubber. The ignitron tanks are cooled by water passed through copper tubing, which is wrapped around the tank and coiled on the bottom, and attached to the steel with high-temperature solder. Additional cooling in high-current units is provided by an internal steel coil. This latter is copper-lined to keep all water-cooled surfaces nonferrous. Figure 2 shows a cross-section view and Figure 3 an external view of the ignitron described.

A rectifier unit consists of a transformer and the rectifier assembly or assemblies to which it is connected. In large-capacity units two or more rectifier assemblies may be connected to one transformer.

Rectifier circuits which efficiently utilize the circuit elements are arranged for three-phase operation and require multiples of three anodes. (Smaller installations are sometimes made with four anodes.) Where the power required can be supplied with six anodes, or where the small number of units suggests sectionalization to insure continuity of service, ignitrons are assembled in groups of six on one frame with one cooling system and one vacuum pumping and measuring system. However, in large stations where ample reserve is maintained with one unit out of service, simplicity dictates assembly in units of 12. Such assemblies have proved most convenient, and one vacuum system of any established type has proved adequate. The individual tanks are connected to the vacuum pumps through a vacuum manifold with water-cooled pumping connections which condense the mercury vapor and prevent transfer of mercury between tanks and pump. On these large-size tubes an individual vacuum valve on each facilitates both manufacture and repair, since vacuum tightness can be checked more easily by isolating smaller elements. Also, one ignitron tube can be treated as an entity and interchanged with a spare in less than one hour if necessary.

Figure 4 shows an assembly of 12 ignitrons rated at 5,000 amperes d-c in the 600-volt class.

All high-power rectifiers have been water-cooled. Since cooling water which is pure enough to pass through the rectifier jackets or tubes directly without trouble due to corrosion or scale is rarely available, practically all installations are provided with heat exchangers which permit the recirculation of pure or treated

Figure 1. Typical ignitron installation in an electrochemical plant

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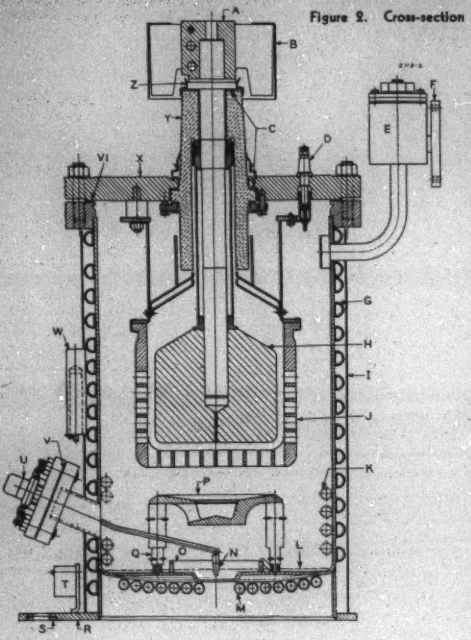


Figure 2. Cross-section view of an ignitron

A—Anode radiator and terminal
B—Radiator cover
C—Asbestos seal
D—Shield entrance bushings
E—Tank valve
F—Vacuum manifold connection
G—Tank-cooling coils
H—Anode head
I—Tank cover
J—Anode shield
K—Internal cooling coils
L—Mercury cathode
M—Cathode-cooling coils
N—Ignitor tip
O—Quartz ring
P—Baffle
Q—Quartz tube
R—Steel plate
S—Copper insert
T—Terminal block
U—Ignitor entrance assembly
V, V1—Aluminum seal rings
W—Thermal switch
X—Anode plate
Y—Anode porcelain
Z—Solder seal

water. Where ample raw water is available, water-to-water exchangers are used, otherwise water-to-air. Water-to-air exchangers are nearly always used in mining installations where cooling water is either not available or of very low quality.

Unit Excitation and Control

The earlier types of ignitron excitation which utilized thyratron tubes have mostly been superseded by circuits which generate impulse voltages by means of saturating reactors.[2] These circuits utilize static devices throughout: that is, simple transformers, reactors, capacitors, and Rectox rectifiers. The excitation-circuit devices, together with the vacuum- and cooling-system control, are mounted in a cabinet located on or near the rectifier. Two types of phase control of rectifier voltage have been used. One is a mechanical phase shifter, which consists of a wound-rotor induction machine. The excitation power is passed through this phase shifter, and the phase position of the excitation impulses is determined by the position of the phase-shifter rotor in its stator. This position is controlled by a fractional-horsepower motor through a gear box. The other type of phase control utilizes some form of phase-shifting network in which the phase position of the excitation impulses is determined by the value of direct current in a saturable reactor. This latter is a less simple circuit than the mechanical phase shifter, but is more flexible where automatic control is required, and speed of response is important. Particularly, the phase-shifting network is suitable for use with a simple type of voltage regulator such as the Silverstat. Also, such a network may be designed to include voltage-compensating characteristics which will maintain full energy excitation through supply-line voltage fluctuations as great as 50 per cent.

Station Layout

The simplest and most economical arrangement of apparatus in a rectifier substation is to effect a straight line run of power from the a-c supply source to the d-c bus. Figures 5 and 6 show a typical multiunit station layout having this arrangement. Incoming power is delivered to the a-c bus, from which it is distributed to the ignitron units through a-c switchgear, the transformers, ignitrons, and d-c switchgear to the d-c bus.

For the layout shown, the a-c switchgear is in a small masonry house separated from the main building. This can be modified to supply conventional outdoor switchgear, outdoor metal-enclosed gear, or the switchgear can be located in the substation building.

All transformer equipment is outdoor. It can be supplied with conventional bushings and an overhead bus structure or with potheads and an underground system as shown.

The substation building is designed with two levels, the ignitrons and all necessary operator control devices being located on the operating floor with some accessories and low-voltage switchgear in the basement. All of the equipment in the basement is operated electrically from the operating floor and is completely supervised by indicating devices. The operator need go to the basement only for routine inspection and maintenance. In many installations the low-voltage switchgear is also located on the operating floor.

Some detail equipment which is required for station operation and which can be located as convenient is not shown. This includes the station battery with charging equipment, the degassing equipment, air-cleaning apparatus if required, storage space for spare parts, and equipment for supplying power to plant auxiliaries which are not associated with the substation equipment.

Building appurtenances such as stairways, lavatory facilities, and operators' office must be included. A repair bay should be provided and is usually at the end of the substation building. Crane facilities and sufficient head room for untanking the largest transformer will determine its construction. An enclosed clean room for working on interior parts of rectifiers is desirable.

Rectifier-Switching Arrangements

Figure 7 shows the several switching arrangements which are in use for ignitron units, rated at 8,000 to 10,000 amperes in the 600 d-c voltage class, in multiunit substations.

Circuit *A* is used when the concentration of power supply to the a-c bus is heavy, a condition which would require large rupturing capacity and costly oil circuit breakers in the rectifier-unit circuits. Circuit breakers are not used, the primary switching consisting of a disconnecting switch which is capable of opening the transformer magnetizing current. For this arrangement, primary faults must be opened by the switchgear in the supply circuit or circuits to the plant. This involves a plant shutdown until the faulty circuit is isolated by operation of the disconnecting switches.

Figure 3. A single ignitron

The secondary switching consists of high-speed anode switchgear with one pole for each phase of the transformer secondary.

High-speed switching, which will limit the d-c rise in the average circuit in the order of one-third cycle, on a 60-cycle basis, is essential for large multiunit substations. At the time of arc back, all normal units will contribute direct current to the arc back in the form of reverse current. This current increases rapidly, depending upon the inductance of the circuit, and must be limited by the switchgear to a value which the switchgear can open successfully and without undue maintenance. It is also advantageous to limit the stresses on the other equipment involved in the circuit, particularly the transformer.

When an arc back occurs, the sound anodes of the ignitron assembly in which the arc back has occurred will supply current to the faulty anode. This feed to the arc back is in addition to the back feed from other ignitron units and is a short circuit, through the arcs involved, on the transformer secondary. This fault must be suppressed by opening the a-c supply to the transformer or by opening the faulty circuit between the transformer and the ignitron.

For arrangement *A*, the a-c supply to the transformer cannot be opened except by operation of the circuit breakers in the station supply. High-speed anode switching is therefore essential for this circuit.

The anode circuit breakers are supplemented by semihigh-speed cathode circuit breakers. These are used for normal switching operations. Disconnecting switches permit maintenance of the circuit breakers with a minimum of equipment out of service.

Circuit *B* is quite similar to circuit *A* except that an oil circuit breaker is used in the circuit to the rectifier transformer. Its use can be justified if the rupturing capacity required is 500,000 kva or less. The circuit breaker is then relatively inexpensive, and each ignitron circuit is completely independent of the others. Circuit faults are isolated without plant shutdown. Complete flexibility of control is afforded.

The use of high-speed anode switching makes it unnecessary to open the oil circuit breaker at the time of arc back. When two ignitron assemblies with independent low-voltage switching are connected to one transformer, the anode switching can be opened for one assembly without affecting operation of the other. This is of advantage in keeping maximum conversion equipment in service. The importance of this feature is in inverse ratio to the number of conversion units normally connected to the common d-c bus.

Circuit *C* is similar to circuit *B* except that the high-speed anode switches are omitted, and a high-speed cathode circuit breaker is substituted for the semihigh-speed switch. With this arrangement reverse current to the ignitron assembly which has arced back is opened with high-speed action by the cathode circuit breaker. Arc quenching may be used to suppress the alternating fault current by preventing the normal anodes of the assembly from firing to the faulty anode. This latter operation is effective in approximately one cycle.

Circuits *B* and *C* are therefore comparable except for two features. Arc quenching sometimes fails in its operation. It is about 90 per cent effective. When it fails in operation, the oil circuit breaker must be opened by overload relay action to remove the fault. Anode switching is fully operative, but there are six poles of switchgear to maintain, compared to a single larger pole of cathode switching. The choice between the two circuits is therefore dictated by consideration of maintenance, as compared with an occasional failure to segregate the fault in a half-rectifier unit.

If arc quenching is not used in connection with circuit *C*, the primary oil switch unit must be interlocked with the cathode switch so that the entire unit is removed from service in the event of arc back, and the a-c short circuit endures for the opening time of the oil switch, which is usually of the order of six cycles.

Circuit *C* makes use of anode disconnecting switches in the anode circuits to each ignitron section, one assembly making up one half of the unit. These are used so that each assembly can be isolated for maintenance and continue with normal operation of its associated assembly. They are also of use during the degassing process.

For those installations, where a complete unit outage is permitted because of spare capacity available, the anode disconnecting switches can be omitted. This applies equally to circuits *A*, *B*, or *C*. Circuit *D* shows a circuit similar to circuit *C* except with the anode disconnecting switches omitted.

For single rectifier units connected to an isolated d-c bus, the switching can be simplified. The unit may consist of one or more ignitron assemblies. For either condition, the amount of current in-

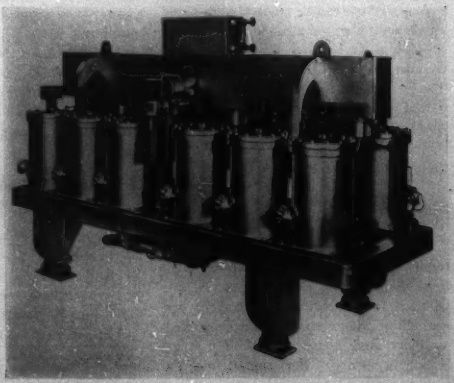


Figure 4. An assembly of 12 ignitrons rated at 5,000-amperes d-c in the 600-volt class

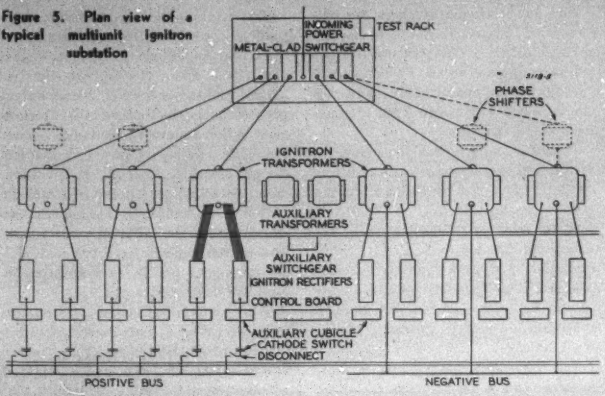


Figure 5. Plan view of a typical multiunit ignitron substation

volved in an arc back is relatively small and semihigh-speed switchgear, having a speed of $1^1/_2$ to 2 cycles to current limitation, is adequate for the service. This may be arranged, as in the case of high-speed switching, either with anode breakers with suitable cathode switching to provide the type of operation desired, or with a cathode breaker and an oil switch in the primary of the transformer. Reverse current for a single assembly is applied from the electrolytic cells. Where a cathode switch is used, an arc back is cleared by the opening of the cathode circuit breaker, followed by the opening of the oil circuit breaker.

For double assembly units, arc quenching can be used in combination with the semihigh-speed cathode switches to secure continuous half-unit operation. Anode disconnecting switches can be used for half-unit isolation. Circuit *E* illustrates the use of semihigh-speed cathode switching with a single rectifier unit supplying an isolated d-c bus.

A special use can be made of high-speed anode switching for a single rectifier unit supplying an isolated load where continuous service is an absolute essential. The switch can be arranged to trip individual poles and on reverse current only. At the time of arc back only the pole of the circuit involved in the fault will open, the other anodes continuing in service.

Station Voltage Control

The great majority of industrial loads requiring one- or two-unit stations, particularly including electric railways, are adapted to the normal five to eight per cent shunt characteristic of noncontrolled rectifiers, and phase control of voltage is not necessary. For applications requiring flatter voltage regulation one of the phase-control systems is used, and there is a wide choice of control method ranging from manual to fully automatic. Provision can be made for flat compounding and cross compounding where more than one unit on a bus is involved. Where small units are located at the end of a low power feeder, which frequently occurs in mines, and the a-c supply to the rectifier transformer varies widely, some form of compensator is used which by phase control reduces the voltage at the lighter loads and provides a nearly flat voltage regulation from light load to full load. Above full load the uncompensated voltage regulation prevails.

In large stations containing many units on one bus, phase control is always used, primarily to compensate for minor differences in impedances and equalize the currents in the several units, and to provide small variations in voltages as desired for the load. However, since large phase-control angles adversely affect power factor and increase harmonics, the minimum feasible transformer tap is used in order to keep the phase control angles at a minimum.

Some electrolytic processes require commercially constant d-c voltage both for initial starting up of the process and for normal operation. For these processes no-load voltage taps can be provided in the rectifier transformers to compensate for seasonal voltage changes and for electrolytic cell aging.

Ignitor or phase control of d-c voltage can be used for short times in the range required to pick up and drop load due to switching requirements. It can also be used for small voltage adjustments over long-time periods of operation.

Some processes require a wide voltage range for initial starting up in order to condition new cells in small blocks, but require essentially constant voltage for normal operation. For these processes an autotransformer of sufficient capacity to supply all rectifiers connected to one or several cell strings in parallel can be supplied. No-load taps are supplied in sufficient number and range to accomplish the desired results. Phase voltage control can be used for d-c voltage adjustment between taps. It is not however recommended for long-time wide-range voltage adjustment, because of its adverse effect on power factor and the increase in harmonics. The autotransformer can also be used for permanent adjustment of d-c voltage when required by a change in production schedule.

Some processes require that constant current be maintained through the electrolytic cells, even though the cell characteristics change frequently and rapidly. For these processes an autotransformer having a combination of no-load taps and tap changer under load can be supplied. The no-load taps cover the extreme voltage range required. The tap changer under load is arranged to boost or buck the d-c voltage from any no-load tap and in the range required. The tap points of the tap changer under load equipment can usually be made sufficiently fine so that phase control of voltage is not required between taps or, if used, will be limited to a few per cent in range. In many processes the fluctuations in voltage required to maintain constant current are so great and frequent as to require pro-

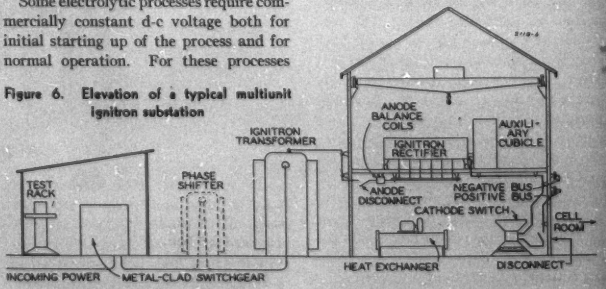


Figure 6. Elevation of a typical multiunit ignitron substation

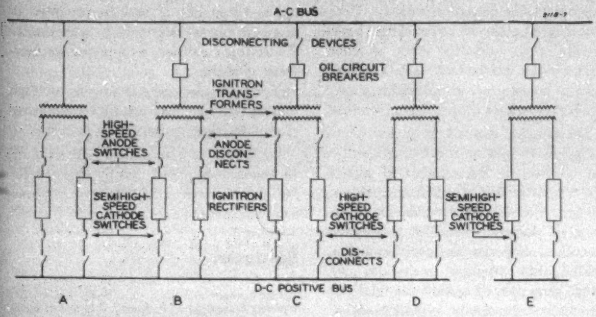


Figure 7. Schematic diagrams showing various arrangements of rectifier switching

hibitive frequency of tap changing or large phase-control angles. In these processes attempts to maintain constant current have been abandoned.

At some locations the demand clause in power contracts is such that high power rates must be paid over a year, because of a short-time swing over the demand ceiling. For processes where load conditions fluctuate rapidly and over considerable range, autotransformers with tap changer under load equipment can be used to secure constant kilowatt input to the cells. This will insure maximum production at the normal power rate, or at minimum power cost. Where more than one station is supplied from the same source, the averaging effect of the several stations proves most advantageous in reducing the number of tap changes required.

Regulation for either constant direct current or for constant kilowatt input can be made full automatic.

Figure 8 shows an autotransformer connected to the rectifier a-c bus, the voltage of which can be varied according to the electrolytic process requirements.

Since the loads on the large station busses constitute practically a short circuit for a single rectifier unit, it is not possible to place units on the bus individually at full voltage following a station outage. Where the power-supply system is large with respect to a single station, it has been general practice to connect all units to the power supply and the a-c bus without excitation, and then to close the excitation contactors to all units simultaneously with a master control switch. Where the supply system is not adequate for this procedure, station phase control of voltage is used. In this method of starting a station following an outage, all units are connected to the bus, either simultaneously as above or individually, but with phase-delay angles set uniformly to limit the station current to a value satisfactory to the supply system or to the rectifier unit, depending on the procedure. The phase-control angles are then advanced uniformly on all rectifier units to increase load to normal at a rate satisfactory to the supply system.

Telephone Interference

A rectifier of any type creates harmonics which are present in the a-c and d-c systems to which it is connected. Harmonics may be induced in telephone lines, which are adjacent to the power systems, under certain conditions of exposure. The telephone-interference problem becomes of increasing importance when the rectifier load is a large percentage of the system load in the exposure areas.

For electrolytic plants, the d-c load is concentrated, and exposures between the d-c circuits and telephone lines are easily controlled. When the a-c power is transmitted a considerable distance, or is supplied from a power network system, exposures are probable, and the telephone interference problem must be considered.

The number of phases at which any rectifier unit can operate cannot be greater than the number of anodes of the unit. Small units having only six anodes are therefore limited to six-phase operation, which operation is used as a base for rectifier harmonic consideration. Since the power involved in a six-anode unit is usually small, the influence on exposed telephone lines is usually too small to be important. As the number of phases in multiples of six are increased, some of the base harmonics of six-phase operation are cancelled, the cancelling increasing as the number of phases is increased. Operation of rectifier units in the higher multiphase relationships, therefore, decreases the telephone-interference problem.

A single rectifier unit of 12 anodes can be supplied from a transformer which is wound to give 12-phase operation. It is not economical to build a transformer for a higher number of phases in a single unit. For those installations which have a large number of rectifier units, multiphase operation can best be secured by operating the units out of phase with respect to each other, and in symmetrical relationship.

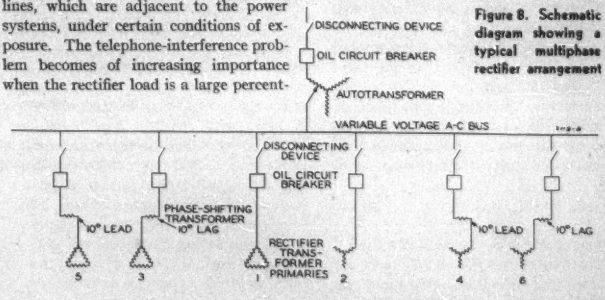
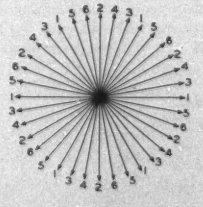


Figure 8. Schematic diagram showing a typical multiphase rectifier arrangement



The combination of two six-phase rectifier units having a delta and a star-connected transformer primary respectively will result in over-all 12-phase operation, since the delta and star are inherently 30 degrees out of phase. The supply voltage to a transformer can be shifted any number of degrees desired by the use of a phase-shifting transformer.[4-6] A combination of delta and star-connected transformers together with phase-shifting transformers can be used to effect any degree of multiphase relationship, the only limit being the number of rectifier units available. For phase arrangements greater than 12, the usual inductances in the circuits are sufficient to provide interphase action.

Table I

Number of Units in Substation	Anodes Per Unit	Base Unit Phases	Maximum Over-All Phase Operation Per Station
1	6	6	6
1	12 or 24	12	12
1	18	6	6
2	6 or 12 or 24	6	12
2	18	6	12
2	12 or 24	12	24
3	6 or 12 or 24	6	18
3	12 or 24	12	36
4	12 or 24	6	24
4	12 or 24	12	48
5	12 or 24	6	30
5	12 or 24	12	60
6	12 or 24	6	36
7	12 or 24	6	42
8	12 or 24	6	48

Figure 8 shows the circuits to the primaries of six rectifier units to secure 36-phase over-all plant operation.

To secure maximum benefit from multiphase operation, the units should be of equal rating, and their loads should be balanced. The impedance of the phase-shifting transformer will result in some unbalance in load between duplicate phase-shifted and unshifted rectifier units, unless some compensation is used. Compensating reactors can be connected in the circuits of the unshifted units, or transformer action can be built into the phase-shifting transformer which will compensate for its voltage drop at any given load.

The benefits secured from multiphase operation are not in direct proportion to the increase in the number of phases. The proportionate benefit from each succeeding increase in number of phases drops off sharply beyond 30- to 36-phase operation. Experience to date has demonstrated that 36-phase operation gives satisfactory operation from the telephone interference standpoint in most cases.

Recently the rectifier load on some power systems has become quite large and concentrated. Spot loading of three or more 36-phase operating groups may be encountered. For these special cases the sheer magnitude of the higher harmonies may be sufficient to warrant an increase in multiphase operation. Also a resonant condition for one or more of the higher harmonics may exist. For these installations operation at 72 or 108 phases may be of advantage.

If one rectifier unit, in a multiphase set-up, is taken out of service, an unsymmetrical phase relationship will result. Under this condition, a 36-phase arrangement gives just as good results as any higher-numbered phase arrangement. Operation with one unit out of service gives reasonably satisfactory results.

By the use of base units connected 6 or 12 phase, as required, and by phase shifting of associated units, the combinations shown in Table I can be secured.

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Low-, Medium-, and High-Pressure Gas-Filled Cable

G. B. SHANKLIN
MEMBER AIEE

Synopsis: After preliminary development work systematic laboratory tests, closely simulating service conditions, were started in 1934 leading towards final development and improvement of gas-filled cable. The first full-size field installation of gas-filled cable was placed in service in 1938. The results of this work up to that time were summarized in an AIEE paper presented at the winter convention, January 1939. The present paper will deal with progress made since then, covering the whole range of voltage ratings from 10 kv to 138 kv, divided as follows: low-pressure gas-filled cable systems 10 kv to 40 kv, operating at gas pressures from 10 to 15 pounds per square inch; medium-pressure systems 40 kv to 69 kv, operating at gas pressures from 24 to 40 pounds per square inch; high-pressure systems 69 kv to 138 kv, operating at gas pressures from 150 to 200 pounds per square inch.

AFTER preliminary development work on gas-filled cable a systematic series of long-time load-cycle endurance tests closely simulating service conditions were started in our laboratories the early part of 1934, and this work is still being continued. These laboratory studies have proved a most useful guide in perfecting gas-filled cable design. They have allowed the best selection of materials and the most effective methods of construction and treatment in the factory.

The first full-sized field installation of gas-filled cable was placed in service during the summer of 1938, and since then quite a number of 15-kv and 27-kv installations have been added. Our first and only published report on gas-filled cable was in the form of an AIEE paper presented at the winter convention, January 1939.[1] It seems an appropriate time to summarize advancements made since then and co-ordinate with field experience.

Gas-filled cable has, we believe, technical merit and advantages that more than warrant its full development. It is simple, economical and of small size. Pressure control means uniform control of both insulation and sheath behavior with a lesser chance of trouble with either. The self-supervising feature is also important in view of the fact that most cable troubles come from sheath defects or damage. Finally, compound migration troubles are eliminated and there is no concern about the contour of the cable run within tensile strength limits of the cable itself. Three-conductor, 27-kv low-pressure cable has been in operation for several years past in vertical tunnel shafts from 200 to 250 feet in depth without trouble of any kind, nor has bleeding of compound from the insulation been any more than experienced in ordinary runs.

Three-Conductor Cable

The theory, characteristics, and design of gas-filled cable were dealt with in some detail in the previous paper and will not be repeated here. Briefly, this cable is similar in materials and construction to ordinary solid-type paper-insulated cable, with the exception that longitudinal gas feed channels are provided for uniform gas-pressure maintenance and control.

For low- and medium-pressure use at voltages up to 69 kv the three-conductor shielded type represents the most practical and economical form, since the gas feed channels can be conveniently located in the three triangular filler spaces that are otherwise merely waste space. Figure 1 gives a good idea of the cross-sectional construction. Two of these gas channels are of open steel spiral construction, giving free access to the insulated and shielded conductors. The third is a solid-wall metal tube filled with dry nitrogen gas and sealed off at each end before treatment of the cable length. The function of this tube after installation will be described later. Vacuum drying and impregnation treatment in a large tank before leading is exactly like that for solid-type cable. After impregnation and while still hot, the compound is drained from the tank, being displaced by dry nitrogen gas. The reel of cable is left in the heated tank until all surplus compound drains off, and only that compound held by capillary attraction in the dense cross section remains. The channels and outer surfaces present a clean appearance, but it is surprising how much of the heavy compound is held in the cable cross section by capillary balance, the finished cable being almost as well filled as a solid-type cable.

The treated reel length is then removed to a nitrogen-filled chamber directly behind the lead press, and the lead sheath is applied under a flow of nitrogen. After end sealing the gas pressure is raised to approximately ten pounds per square inch and the cable length is maintained at this pressure until ready for splicing in the field. Before the shipping reels leave the factory, the whole cable cross section is saturated with nitrogen to the same pressure as that in the gas feed channels. This assists greatly in maintaining uniform cross-sectional pressure in service.

Joints

Figure 2 shows a typical three-conductor joint. With exception of the tube insert connections and the fact that the lead casing is filled with nitrogen gas instead of compound, the joint is the same in construction and size as an ordinary solid-type cable joint, the same method of con-

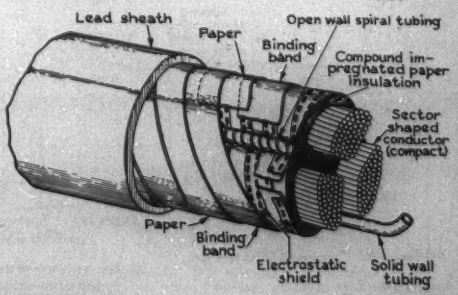

Figure 1. Three-conductor gas-filled cable

Cut-away view showing details of construction

Paper 42-102, recommended by the AIEE committee on power transmission and distribution for presentation at the AIEE summer convention, Chicago, Ill., June 22-26, 1942. Manuscript submitted April 2, 1942; made available for printing April 27, 1942.

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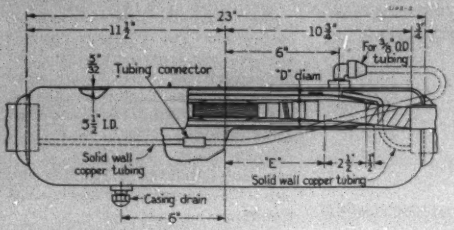


Figure 2. Normal joint

For 27-kv three-conductor gas-filled cable

necting, stepping, reinforcement taping, and shielding being followed. In preparation for splicing, the cable pressure is lowered to about two pounds, the ends are cut, conductors are spread, and temporary sponge rubber seals are applied in the crotch to prevent appreciable loss of gas during the remaining operations. The total time is the same as that required for constructing a corresponding solid-type joint, because of the fact that the time required for the special operations is compensated for by the absence of compound filling operations.

Pressure Control

The primary function of the solid-wall metal-tube insert in the cable is to furnish a by-pass path for gas flow at low points or dips in the cable run, where slugs or surplus compound might gradually form in the open channel spaces during initial periods of heavy load, or during hot summer weather. The method of interconnecting the tube ends and the joint casing, as shown in Figure 2, traps any compound that might enter the casing and assures a free gas path and uniform pressure control over the entire length of the cable line. The lead sleeve casing in Figure 2 is shown eccentric, the bottom part acting as a sump for collection of surplus compound. It has since been found that an ordinary concentric casing gives sufficient capacity for this purpose.

Field tests have shown that, with the help of this tube insert, pressure can be controlled at one terminal end only of lines up to about ten miles in length. A pressure relay at this one location will give an indication of gas leakage at any point in the line, and when loss of pressure occurs, additional gas can be injected from an emergency storage cylinder until the leak can be located and repaired. Where feasible, pressure control and relaying at both ends of long lines is desirable but not necessary.

The first installations of gas-filled cable, as described in the previous paper did not have the metal-tube insert. They are operating successfully, and there has not been any special trouble in maintaining and controlling pressure. It is necessary, however, or at least advisable, to "blow out" the cable line periodically with nitrogen gas and make sure the channels are sufficiently clear of compound to transmit gas pressure. The metal-tube by-pass insert has completely eliminated this need, and there is no question but that it simplifies and facilitates operation of three-conductor gas-filled cable.

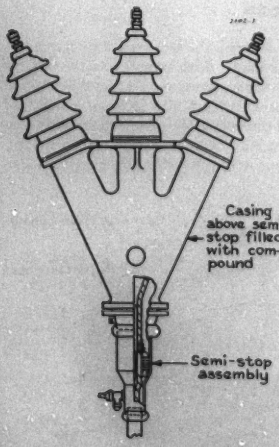


Figure 3. Compound-filled terminal

For 34.5-kv three-conductor gas-filled cable

Terminals

A typical soft compound-filled, three-conductor terminal for gas-filled cable is shown in Figure 3. The only departure from terminals used with solid-type cable is the semistop gasket assembly in the base to prevent the soft compound from draining into the cable channels. A simpler all-gas-filled terminal without the semistop has been developed for use at 15 kv and is also being made available for higher voltages. Both kinds of terminals are also designed as single-conductor and spreader three-conductor types. The only difference between terminals for low-pressure cable (10 to 15 pounds per square inch) and medium-pressure cable (25 to 40 pounds) is that heavier porcelains are required to withstand the higher gas pressure.

Single-Conductor Cable

The gas feed channel for single-conductor cable is in the form of an annular space directly under the lead sheath as shown in Figure 4. Copper tape with stamped button spacers centers the insulated shielded conductor and gives support to the lead sheath. In comparison, the single-conductor cable is less economical than the three-conductor type, because of the increased over-all diameter and cost this channel construction represents. In the three-conductor cable decreased insulation thickness and smaller diameter compensate for the extra gas operations in the factory and field, and the costs of low-pressure gas-filled cable and of solid types are practically the same. Single-conductor gas-filled cable, however, is of higher cost than equivalent solid type, because of the channel requirements mentioned.

This handicap is not very serious and in large sizes the low-pressure single-conductor type has found a useful place as primary station tie cable where numerous vertical runs are encountered. Absence of compound migration troubles and the self-supervision obtained from gas pressure control justify the extra cost. Another promising field for single-conductor gas-filled cable is for power transmission at 46 kv and above, when the load per circuit is too large or the ducts too small for three-conductor cable. In this voltage range medium-gas-pressure operation is more economical than low

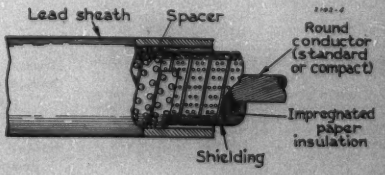


Figure 4. Single-conductor gas-filled cable

Cut-away view showing details of construction

pressure, as will be discussed later, and the further reduction in insulation thickness gained thereby offsets the added cost of the gas channel construction.

The solid-wall tube insert for by-passing compound slugs, such as used in three-conductor cable, is not well adapted to single-conductor construction. This is largely overcome by paralleling the gas connections at each manhole of the three cables making up one circuit, assuring three separate paths for gas flow. The possibility of slug formation in all three cables at one time, in one location, and of sufficient number to materially interfere with pressure control, is remote.

Ionization as a Function of Gas Pressure

A fundamental and important characteristic of gas-filled cable is clearly brought out by a study of Figure 5, which shows ionization starting voltage as a function of gas pressure. A similar curve was given in the previous paper. At that time we had only limited test data above 15-pound pressure and little operating experience to confirm test results. Additional data obtained since allow a more accurate construction of this curve. It closely simulates operating conditions, in that it shows ionization voltage after capillary balance has been reached from load-cycle bleeding of compound, but before appreciable wax formation from test overvoltage has started.

The earlier paper described the self-extinguishing and self-healing properties of wax formation in voids of gas-filled cable. Further work has fully confirmed this important characteristic. It offers an additional factor of safety at those locations along a cable line where ionization might get started. Expressed in another way, gas pressure and ionization control automatically eliminate weak spots and result in more uniformity along the cable length. This in turn allows working voltage stress to more safely approach the critical voltage stress at which cumulative ionization deterioration occurs.

The whole question is whether the measured ionization starting voltage curve in Figure 5 represents this critical voltage stress or something less. From all of the evidence we have obtained it is the writer's opinion that the curve in Figure 5 is something less than critical stress and is actually a goal representing an upper limit of safe working stress in service to be approached as more experience is gained. There are sound reasons for believing this.

First, it has already been proved by numerous long-time load-cycle tests at pressures up to 30 pounds per square inch that gas-filled cable remains stable at stresses considerably higher than represented by the curve in Figure 5. Instability and ultimate breakdown on these tests occur at stresses from 40 to 70 per cent above the Figure 5 curve.

Admittedly, laboratory tests on relatively short lengths are not conclusive in establishing safe working stresses until confirmed by field experience. We have had confirming field experience of this kind with low-pressure gas-filled cable operating during recent years at an average gas pressure of 12 pounds per square inch and an average voltage stress of 65 volts per mil. Reference to Figure 5 will show that at this pressure ionization starts at 80 volts per mil. Accordingly, operating experience has been at a stress only 15 volts per mil less than this. No service failure has yet occurred in gas-filled cable systems and no signs of ionization have been detected. One length of 27-kv cable was removed for test after one year of service. It was found to be in perfect condition. This experience would indicate that there is a good margin of safety and some latitude for increasing present working voltage stress. It also indicates that uniformity in the field is under the same control as obtained in the laboratory on relatively short test lengths.

Additional proof that the initial ionization versus pressure curve in Figure 5 represents a stable and safe condition is found in the characteristic behavior of all representative lengths on long-time load-cycle tests. Typical test results of this kind are shown in Figures 6 and 7. Figure 6 is a chart of the whole test in terms of power-factor stability. Three load cycles per day from room temperature to 80 degrees centigrade were applied, and the gas pressure was maintained at ten pounds per square inch cold and not more than 14 pounds hot. It will be noted that the test was started at 85 volts per mil, only slightly above the ionization-pressure curve in Figure 5. After stabilization was assured, the voltage was increased, and these steps were repeated until final failure occurred after 16 days at 120 volts per mil.

Figure 7 gives power-factor voltage curves on this length as measured initially and at the end of each voltage step shown in Figure 6. Initial ionization at

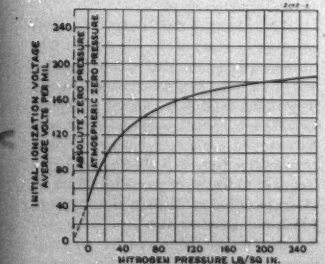


Figure 5. Ionization voltage versus gas pressure

Average voltage stress on solid insulation at which initial ionization starts in gas-filled cable after full drainage of compound but before endurance-test voltage is applied

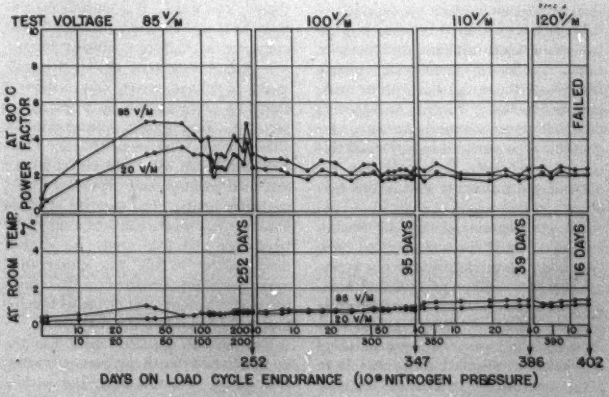


Figure 6. Load-cycle endurance at ten pounds pressure

Three-conductor gas-filled cable of standard construction, with exception that inner 50 per cent of insulation wall consists of three-mil paper tape instead of usual six-mil tape. Total insulation thickness 0.200 inch

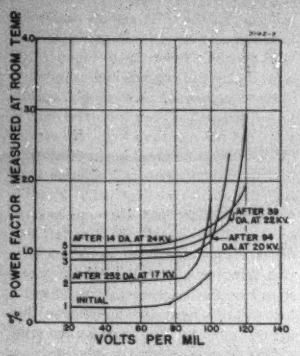

% POWER FACTOR MEASURED AT ROOM TEMP
VOLTS PER MIL
AFTER 14 DA. AT 24 KV.
AFTER 30 DA. AT 22 KV.
AFTER 94 DA. AT 20 KV.
AFTER 232 DA. AT 17 KV.
INITIAL

Figure 7. Ionization during load-cycle test

Showing increase in ionization starting voltage, due to wax formation, during different stages of the load-cycle endurance run charted in Figure 6

ten pounds pressure, and before wax formation started, was at 77 volts per mil (equivalent to 80 volts per mil at 12 pounds). Wax formation in the voids extinguished ionization, and the cable became stabilized in about 70 days, thereby automatically raising the ionization voltage to a value equivalent to endurance test voltage. This was repeated each voltage step until the last, 120 volts per mil. Here the stress was too high for the same kind of stabilization to take place and failure occurred in a few days.

If space would allow, additional evidence could be offered showing that the initial ionization-pressure curve in Figure 5 is a useful and practical guide in the design of gas-filled cable systems. Insulation thickness is an important economic factor in such design work. Figure 5 gives a direct indication of insulation thickness requirements as a function of working gas pressure. Increase in pressure means lesser insulation and a smaller cable. The higher the operating voltage, the greater the saving that can be made in this direction. There is an opposing economic factor however. An outer covering must be provided to withstand this gas pressure safely, and the higher the pressure the greater the cost of this covering.

Due consideration of these factors has led to a logical division of gas-filled cable design into three classifications or types, low-pressure, medium-pressure and high-pressure systems. Each covers a certain economic range of voltage ratings. All three have in common the general characteristics of gas-filled cable that have been described. Individual features, limitations, and advantages will be briefly outlined.

Low-Pressure Systems

The low-pressure system has already been described. Aside from comments on pressure control and leak location, only those features that distinguish it from medium- and high-pressure systems will be dealt with here.

Experience has shown that the normal gas capacity of the cable itself and the joint casings are sufficient to limit pressure fluctuations from daily load cycles to a range of only one to two pounds. It accordingly is not necessary to use automatic pressure-regulating equipment. Seasonal adjustment of pressure by hand to an average working value of 12 pounds per square inch is all that is necessary. An ordinary high-pressure storage cylinder of nitrogen is connected permanently to the cable line through a reducing valve. An exhaust valve is also provided. Normally these valves are closed. During routine inspection and for purposes of compensating for seasonal temperature changes, average working pressure is readjusted to 12 pounds by hand manipulation of these valves. If there is a loss of pressure in between these periods, a pressure relay gives notice when minimum pressure drops to ten pounds.

Leak location is not a difficult matter. It is first necessary to disconnect the external tube by-pass fittings on the joints (Figure 2) at intervals along the line and insert pressure drop reading devices. A graph plot of these readings indicates the point of leakage. The pressure-reading devices can be left permanently connected if desired, and one utility prefers this. Obviously, small slow leaks require a longer time and closer readings to locate than do fast leaks. It is entirely feasible to make these lines gas-tight initially and maintain this tightness without trouble.

It has already been shown that safe working voltage stress and insulation thickness are governed by working gas pressure. This, in turn, is determined by allowable hoop stresses in ordinary single lead sheath that will avoid sheath fatigue and hold creepage and expansion within negligible limits. The question of stress limits for lead sheath has been a subject of laboratory and field study for a good many years. A safe and conservative average working stress limit of 125 pounds per square inch of sheath cross section for copper bearing lead is well established.

Low-pressure gas-filled cable has the same standard sheath thicknesses as solid-type cable. On this basis and with a stress limit of 125 pounds an average working gas pressure of 12 pounds per square inch results. Present day insulation thicknesses for low-pressure gas-filled cable represent an average working voltage stress of from 65 to 68 volts per mil. Reference to Figure 5 will show this practice safe and conservative.

These design limitations of insulation and sheath properties and dimensions automatically set the economic voltage range. This range is found to be from 10 kv to 40 kv, and within these limits the cost of three-conductor low-pressure gas-filled systems is closely comparable to the cost of other available types of cable systems.

Above 40 kv, the proportionate saving in insulation thickness makes increased working gas pressure economical in spite of increased cost of the outer covering. This leads logically to medium-pressure systems for moderately high-voltage service.

Medium-Pressure Systems

In theory and principle there is no difference at all between low- and medium-pressure systems. Accessory design and methods of manufacture, installation and operation are the same for both types.

There are two available methods of sheath construction that allow increase of gas pressure:

(*a*). Reinforced sheath.

(*b*). Substitution of a special alloy sheath of greater creep strength than ordinary single sheath.

Both constructions are fully developed. The latter is economically the most promising, but both will be dealt with. It would be well, however, to first consider results of long-time load-cycle stability tests at medium pressure.

A typical test of this kind at 30 pounds pressure is charted in Figure 8. The three-conductor shielded-type cable used was of the same general construction and dimensions as that in Figure 6, having 350,000-centimeter compact sector conductors and 0.200-inch insulation. For comparative test purposes this size and a length of 75 feet were standardized for all of our gas-filled cable tests, the details of which are given in the previous paper. Standard compound was used for impregnation. Strand shielding with paper-backed aluminum tape was also used. Further tests with and without strand shielding will be discussed later, but it will be said here that, as far as load-cycle aging tests on gas-filled cable are concerned, strand shielding appears to im-

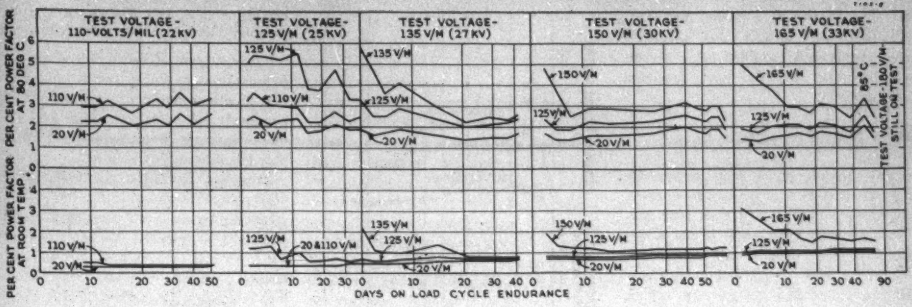

TEST VOLTAGE - 110-VOLTS/MIL (22KV)
TEST VOLTAGE - 125 V/M (25 KV)
TEST VOLTAGE - 135 V/M (27 KV)
TEST VOLTAGE - 150 V/M (30KV)
TEST VOLTAGE - 165 V/M (33KV)
PER CENT POWER FACTOR AT 80 DEG C
PER CENT POWER FACTOR AT ROOM TEMP.
110 V/M
20 V/M
125 V/M
135 V/M
150 V/M
165 V/M
85° C
TEST VOLTAGE - 100 V/M STILL ON TEST
DAYS ON LOAD CYCLE ENDURANCE

Figure 8. Load-cycle endurance at 30 pound pressure

Three-conductor gas-filled cable of standard construction, with exception of aluminum-paper strand shielding. Total insulation thickness 0.200-inch. No-load nitrogen gas pressure held at 30 pounds per square inch (medium pressure)

part no special benefit. This is due to the fact that voids, ionization, and wax formation are distributed uniformly in the butt spaces through the wall of insulation and do not concentrate at the conductor surface alone.

Referring to Figure 8, the 30-pound load-cycle test was started at 110 volts per mil. According to Figure 5, this is the initial ionization starting voltage at this pressure. There were practically no signs of ionization or instability at this stress, so after 50 days test voltage was increased to 125 volts per mil. Here, ionization was apparent but was extinguished after 15 days because of wax formation. As soon as there was assurance of stability (40 days) the test voltage was increased to 135 volts per mil. The same method of stepping voltage was followed to the end of the chart, and it will be noted that self-healing action and stability were retained at 165 volts per mil. This length is still on test at the present writing at 180 volts per mil without signs of failure.

It might be concluded from this test that an increase in gas pressure from 10 to 30 pounds imparts more benefit than would be indicated from the initial ionization curve in Figure 5. However, it appears sounder to use Figure 5 as a guide and not depend too greatly on self-healing action in service, even though it does appear more pronounced as gas pressure is increased. On this basis we believe that an operating stress in the order of 95 volts per mil is safe and conservative at 30 pounds pressure.

Double Reinforced Sheath

Double reinforced sheath was developed originally for oil-filled cable and has been used extensively for this purpose. There have been a good many years of experience at pressures from 30 to 40 pounds per square inch. Based on this, we believe 40 pounds a safe top limit and have designed medium-pressure gas-filled cable with this type of sheath for an average working pressure of 35 pounds and an operating voltage stress of 100 volts per mil. The economic voltage range is from 40 kv to 69 kv.

The double reinforced sheath consists of treated paper and copper tape reinforcement, sandwiched between inner and outer sheaths. The cost is higher than that of ordinary single sheath. Insulation reduction from increased gas pressure does not fully compensate for the increased cost of sheath. Accordingly, the cost of this type of three-conductor medium-pressure cable is higher than that of equivalent single-sheath oil-filled cable. Accessories however are simpler and less costly, as are also installation operations in the field. The result is that over-all costs of the two types of cable systems are not far apart.

High-Creep-Strength Alloy Sheath

From the beginning we have appreciated the economic possibilities of substituting an alloy sheath of higher creep strength than ordinary copper-bearing lead sheath. The requirements are exacting and proved difficult to attain. Such an alloy must retain all of the desirable and proved properties of copper-bearing lead, plus a sufficient increase in long-time creep strength to allow a real increase in working gas pressure. The requirements to be met are:

(*a*). At least twice the long-time creep strength of copper-bearing lead at operating temperatures.

(*b*). A reliable source of supply at reasonable cost.

(*c*). Readily adapted to sheath-extrusion methods in the factory.

(*d*). Equally resistant to corrosion, vibration, bending movement, and aging.

Out of a number of possible lead alloys investigated in recent years the calcium alloys of lead are the most promising, and one in particular, Asarco, will be dealt with. Figure 9 shows the long-time room-temperature creep strength in comparison with that of copper-bearing lead. Similar tests at 100 degrees centigrade plainly show that increasing the average working stress from 125 pounds per square inch for copper-bearing sheath to 250 pounds for Asarco sheath is conservative.

This means that with present standard thicknesses of single lead sheath we can, by using such an alloy, safely increase working gas pressure to 24 pounds per square inch, and corresponding voltage stress to 90 volts per mil, a gain of 38.5 per cent in voltage rating as compared with low-pressure systems operating at 12 pounds pressure. For the same voltage rating the corresponding reduction in insulation thickness is 27.5 per cent.

Regardless of whether the object is to increase voltage rating or to decrease insulation thickness for a fixed voltage rating, this theoretical gain is more or less offset by the increased costs of the special alloy sheath, and the lower the voltage rating the more pronounced this offset becomes. Because of these conflicting cost factors, this particular type of medium-pressure system, like the double reinforced sheath system previously described, has an economic voltage range from 40 kv to 69 kv. Below 40 kv the saving practically disappears, and much above 69 kv, such as 115 kv for instance, three-conductor cable becomes too large to be economical. There is some promise, however, in single-conductor cable above 69 kv. Here the extra cost of the gas-channel construction and the alloy sheath

are offset by the other savings described. All told, we consider this simplified medium-pressure gas-filled cable system an important technical and economic advancement.

High-Pressure Systems

Full advantage of high-gas-pressure operation can only be realized by drawing the cable into a welded steel pipe line. There have been proposals to use a special double lead sheath construction, reinforced for both radial and longitudinal strains, to operate at gas pressures as high as 200 pounds per square inch. This type of cable could be installed in underground ducts in the usual manner which is an advantage, but there appear to be two serious obstacles.

1. The over-all cost is too high in comparison with other available cable systems, such as oil-filled, medium-pressure gas-filled, and, finally, high-pressure gas-filled drawn into steel pipe.

2. There is serious doubt of the feasibility of safely operating reinforced sheath at such high pressures, because of mechanical strength limitations.

There is no doubt but that the steel pipe construction is the most promising, and further comments will be confined to that type.

When properly designed and installed, the high-pressure gas-filled pipe cable system is technically sound and economically attractive. It has however certain limitations that should be fully understood.

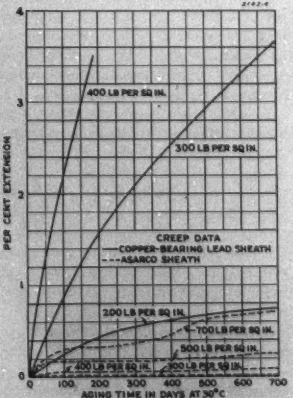

400 LB PER SQ IN.
300 LB PER SQ IN.
CREEP DATA
COPPER-BEARING LEAD SHEATH
ASARCO SHEATH
200 LB PER SQ IN.
100 LB PER SQ IN.
500 LB PER SQ IN.
400 LB PER SQ IN.
300 LB PER SQ IN.
PER CENT EXTENSION
AGING TIME IN DAYS AT 30°C

Figure 9. Creep properties of lead sheath

Long-time room-temperature creep properties of Asarco and copper-bearing lead sheaths. Tests started two weeks after extrusion

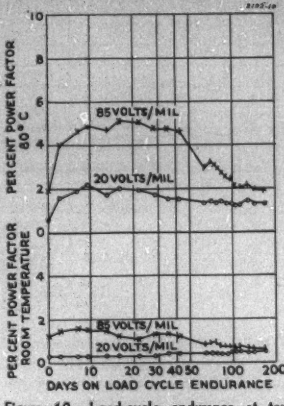


Figure 10. Load-cycle endurance at ten pounds pressure

Standard three-conductor gas-filled cable with aluminum-paper strand shielding similar to cable in Figure 8. No-load nitrogen gas pressure held at ten pounds per square inch (low pressure). Cable still on test at 100 volts per mil

1. It is best adapted to direct burial in open ground, and its use is likely to be limited in this country where most underground systems are in congested areas under paved city streets. The standard duct and manhole construction (and the flexibility it represents) has always proved superior to direct burial under these conditions.

2. Important high-voltage tie-line loads in this country are growing, and the steel pipe cable system is not well adapted to handle extra heavy loads. It is not possible to use one single-conductor cable per pipe, with three pipes spread out to better dissipate copper losses. Instead, it is necessary to draw all three cables into one congested pipe, and the losses to be dissipated are much higher. In this respect pipe cable is no different from other forms of three-conductor cable and has the same well-recognized limitations for economic loading.

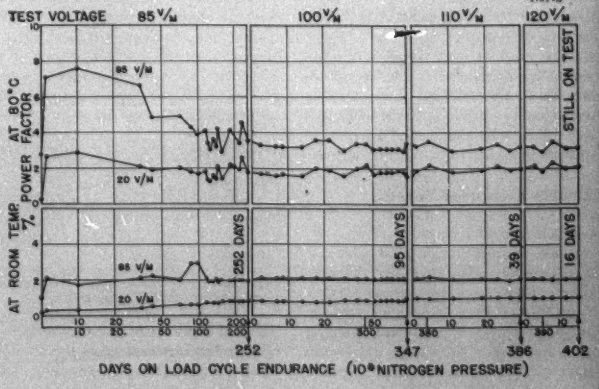
These aspects of the problem are not so important in Europe where the practice of direct burial in open ground is commonly followed, and where load requirements per circuit average considerably less than in this country.

From an insulation standpoint gas-filled pipe cable offers no difficulties. Reference to Figure 5 will show that at 200 pounds pressure initial ionization is at 180 volts per mil. In view of greater self-healing properties from wax formation at high pressures, we could probably operate with safety at an average stress not less than 160 volts per mil. In this respect high-pressure gas-filled cable, like oil-filled cable, has greater 60-cycle strength than can be utilized. Insulation thicknesses for oil-filled cables are based on transient voltage requirements rather than normal 60-cycle rated voltage stress, and the same thing should hold for high-pressure cable. Accordingly, insulation thicknesses for high-pressure gas-filled cables are the same as for oil-filled cable, the rated voltage stress varying from 126.5 volts per mil at 69 kv to 142.5 volts per mil at 138 kv.

Figure 5 shows that this range of voltage stresses is conservative at 200 pounds pressure. In fact, the gas pressure could be reduced to 125 pounds without danger. There is no particular object, however, in not taking advantage of the higher factor of safety offered by the higher pressure, since standard steel pipe will withstand

Figure 11. Load-cycle endurance at ten pounds pressure

Standard three-conductor gas-filled cable exposed to room air for eight hours before applying the lead sheath. Chart shows the effects of oxygen absorption during exposure



200 pounds pressure just about as well as 125 pounds.

Details of pipe construction, welding, covering for corrosion protection, joint sleeves, compressed air test for leakage, and so forth will not be dealt with here, since this practice is well-known and common to all of the various pipe cable systems, of which there is a number of installations in Europe and a few in this country.

Sheaths Intact

After the pipe is laid and ready to receive the gas-filled cable, the remaining operations vary, depending upon whether the sheaths on the three single-conductor cables are left intact or stripped off as the cable lengths are drawn into the pipe. Each of these two methods has advantages and disadvantages that need careful balancing. For loads involving conductor sizes above approximately 750,000 circular mils, short-circuited sheath losses become so great that there is not much choice, economy dictating removal of the sheaths. For lighter loads and smaller conductor sizes there is much to be said in favor of leaving the sheaths intact, but it is difficult to draw an exact dividing line between these two practices without studying each specific case.

With sheaths intact the methods of manufacture, shipment, installation, and splicing are exactly the same as already described for low-pressure systems in ducts, the only difference being that the gas channel between the insulated shielded conductor and the sheath is smaller and simpler than shown in Figure 4, an open spiral wrapping of fibrous tape being substituted for the metal button spacer tape. Each joint is enclosed in a wiped lead sleeve, and since splicing is done under a slow flow of nitrogen gas, the cable insulation is at no time exposed to air or moisture. It is not necessary to remove these impurities from the pipe until the whole line is completed. At that time the pipe can be dried out by short-circuit current in the conductors, or circulation of hot air, or both. Afterwards, the dry air in the pipe is washed out by nitrogen flow assisted, if desired, by drawing a rough vacuum first. These same operations can be done piecemeal on sections of the line as completed if more convenient, and the finished sections maintained at a few pounds nitrogen pressure.

After the whole line is ready, the outlet plugs in all lead joint sleeves are removed, the plugs in the outer steel sleeves replaced, and the gas pressure is brought up to 200 pounds. There is then an interconnection of gas pressure between cable and pipe at every joint sleeve. Equalized pressure throughout removes any question of stress burden on the lead sheaths.

If future repair work, involving replacement of cable lengths, is ever required, these operations are reversed. After lowering the gas pressure, outlet plugs in the lead joint sleeves are replaced, segregating the cable from the pipe. Replacement of cable can then proceed as with low-pressure cable, and at no time is the insulation exposed to moisture and air absorption.

Sheaths Stripped Off

In addition to elimination of sheath losses and reduction in conductor size obtained thereby, stripping of sheaths as the cables are drawn into the pipe has one other advantage. The removed lead can be salvaged. The disadvantages are:

(*a*). An outer tape wrapping and copper armor are necessary for protection during pulling.

(*b*). Extra cost and time for stripping the sheath and protecting cable ends from exposure.

(*c*). Pipe must be dried and filled with nitrogen gas piecemeal before the cable is pulled in, and pulling must be done under a slow flow of nitrogen.

(*d*). Absorption of air and moisture during unavoidable exposure will increase dielectric losses and require a heavier wall of insulation than when sheath is left intact.

(*e*). Future repair work without undue exposure of insulation is more difficult and complicated.

Comparative over-all installed costs and service records will be required before the relative merits of these two high-pressure gas-filled cable systems can be finally decided in those cases where sheath losses are not a dominating factor.

Summary of Recent Test Results

Space will not allow a detailed presentation of all the test data obtained on gas-filled cable since the last published report. We have carried out comparative test studies of the best available impregnating compounds, particularly as a function of viscosity, the effects of paper thickness, strand shielding, exposure to air, further tests on the effects of gas pressure, and some impulse tests. Conclusions drawn from these tests will be summarized, and pertinent results relating to these conclusions given.

Thickness of Paper Tape

The load-cycle test in Figure 6 represents a test length of cable with the inner half of the insulation composed of three-mil paper tape instead of the usual six-mil tape. In all other respects this length was of standard construction. Theoretically, thinner tape means smaller butt space voids and higher ionization voltage. Actually, Figure 7 shows that ionization voltage was no higher than usually obtained with standard six-mil tape. Standard cable retains stability up to 100 volts per mil on load-cycle test at ten pounds pressure and ultimately fails at 110 to 120 volts per mil. The thin paper length in Figure 6 lasted little if any longer, failing in 16 days at 120 volts per mil. In view of the fact that thin tape is more expensive and difficult to apply, tends to wrinkle more, and will not withstand cable bending as well, it is doubtful that there is any benefit that overbalances these disadvantages.

Strand Shielding

It has already been explained that the test length represented in Figure 8 had strand shielding, and the test results did

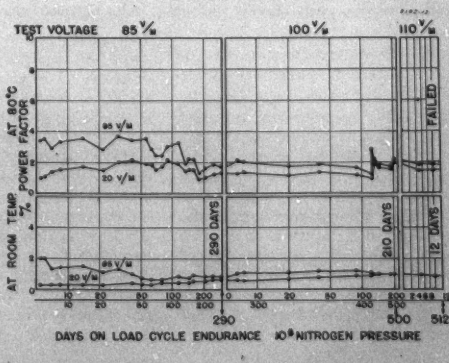


Figure 12. Load-cycle endurance at ten pounds pressure

Three-conductor gas-filled cable of standard construction, with exception that viscosity of impregnating compound was increased to 350 Saybolt at 100 degrees centigrade by addition of 1.5 per cent soluble synthetic compound

not appear to show any particular improvement in ionization characteristics over equivalent cable without strand shielding. This is confirmed by load-cycle tests on an additional strand-shielded length as given in Figure 10. Ionization starting voltage is no different, and it required about the same length of time (75 days) to stabilize at 85 volts per mil as experienced with standard lengths without strand shielding. The length in Figure 10 is still on test at increased voltage stress. Possibly ultimate results will show some benefit from strand shielding, but we haven't found it yet. The explanation seems to be that ionization and wax formation occur more or less uniformly in butt spaces throughout the insulation thickness and do not concentrate at the conductor surface alone.

Exposure to Air

To study the effects of casual exposure to air, as may happen in jointing operations or through some accidental exposure, a standard test length was exposed to room air for eight hours after removal from the treating tank and before the lead sheath was applied. The results of load-cycle testing are given in Figure 11. It will be noticed that oxidation action from the absorbed air increased dielectric power factor at both room temperature and 80 degrees centigrade, the latter increasing to about double that met with in standard cable. It will also be noticed that in spite of this the cable had good endurance and was removed from test after 16 days at 120 volts per mil without failure. The conclusion can be drawn that, within accumulative heating limits, oxygen absorption does not affect voltage endurance but does appreciably increase dielectric loss and should be avoided for this reason. This is particularly true of medium- and high-pressure systems operating at the higher voltage ratings, where liberties with impurities and dielectric loss cannot be taken without serious risk.

Effects of Compound Viscosity

The series of tests we have carried on over a period of years on gas-filled cable indicate rather definitely that there is such a thing as optimum viscosity of impregnating compound and that this is in the order of 100 Saybolt at 100 degrees centigrade, representing the standard all-mineral compound used for some time past. We invariably obtain better results with this compound than with either thinner or heavier impregnants, apparently for reasons explained in the previous paper.

Check tests, that will not be given, again show that thin oil, such as used in oil-filled cable and having a viscosity of 37 Saybolt at 100 degrees centigrade, drains too freely from the insulation and results in poor ionization and endurance characteristics. This is not surprising and would be expected from theoretical considerations. The surprising thing is that various high-viscosity compounds give from fair to very poor results, but even the best shows no advantage over the standard compound.

We have tried about all of the recognized available types of high-viscosity compounds, including rosin mixtures, soluble synthetic mixtures, and hydrogenated oil, with viscosities from 200 to more than 1,000 Saybolt at 100 degrees centigrade. All of these, with one exception, gave poor and unstable results that are hardly worth showing. The best consisted of standard compound mixed with 1.5 per cent soluble synthetic to give a viscosity of 350 Saybolt at 100 degrees centigrade. An incomplete test on a length impregnated with this compound and designated as test length 8, was reported in the previous paper. The complete test is charted in Figure 12. The results obtained from both an ionization and voltage-endurance standpoint were about an average of those obtained with standard cable.

Since extra high-viscosity compound means longer periods of impregnation treatment and drainage, and more difficulty in clearing out gas feed channels, we have, as yet, found no advantage that would justify its use. A study is also being made of preimpregnated tape and, so far, no advantages have been found that would justify its complications and greater cost. Further and more complete tests may modify this belief.

Impulse Tests

After 21 days of vertical drainage with 75-degree-centigrade load-cycles five lengths of single-conductor, 1,000,000-circular-mils gas-filled cable, without strand shielding and having 0.203-inch insulation, were subjected to standard impulse breakdown at a gas pressure of ten pounds per square inch. An average breakdown of 367 kv was obtained with a deviation of 35 kv, or 9.6 per cent. This corresponds to an average stress of 1,800 volts per mil, compared with an average of 1,680 volts per mil obtained on 33 lengths of ordinary solid and oil-filled cable. On the basis of maximum stresses, which some prefer, the gas-filled cable gives 2,130 volts per mil, and the solid and oil-filled, 2,260 volts per mil. For all practical purposes it can be said that the results on all three types are closely the same. It is reasonable to assume that the same thing would hold for medium- and high-pressure gas-filled cable, since the insulation thickness is not under compression and does not vary with pressure.

Reference

1. Low-Gas-Pressure Cable, G. B. Shanklin. AIEE Transactions, volume 58, 1939, July section, pages 307–18.

Improvements in Preventive-Coil Control for A-C Locomotives With Particular Reference to Resistor Transition

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SINCE the original development of the a-c locomotive there have been many attempts to improve the locomotive control over that provided on early designs.

Control problems have come under three general classifications, namely:

1. Voltage control for the acceleration of the locomotive.

2. Functional control for adjusting various fields of the series traction motor for best commutating characteristics.

3. Protective relays for protection of locomotive and traction motor circuits from grounds and faults of various kinds and for protection of the traction motor from overspeeding.[1,2]

This article will deal only with the first of these problems, namely, those incident to the voltage control as it relates to accelerating a locomotive, with particular reference to a new development in the art. The new development is the resistor transition scheme for switching preventive coils from one pair of transformer taps to the next. A résumé of service experience with a locomotive so equipped is also included.

While the search for a better method of acceleration has proceeded, there have been no revolutionary improvements made, and progress has been essentially a refinement in design.

Early locomotives made use of a switching reactor, or preventive coil, in tapping from one set of transformer taps to the next, and the scheme which developed the most favor soon grew to what was termed as the three-preventive-coil notching scheme. In this scheme two small preventive coils feed a large preventive coil which in turn feeds the traction motor circuits through its mid-tap. The two small preventive coils are connected to two sets of bus bars, which are connected by tap switches to the main transformer taps in the correct order. Each tap switch carries one quarter of the load current in the normal design where all preventive coils have their mid-tap equidistant from the two end terminals. The three-preventive-coil scheme of control has persisted and is now the scheme most generally used on a-c locomotives in the United States.

During recent years several voltage-control schemes of a somewhat different nature have been devised and in some instances have been tried out in service both in this country and abroad, but by and large the schemes have met with indifferent success. Schemes tried in this country include one that has used a relatively large buck-boost transformer, the primary of which is controlled by means of light-current relatively high-voltage switches. When the large buck-boost transformer has been notched up to its maximum voltage, balanced voltage conditions are obtained. This condition is retained through suitable transfer switches while the buck-boost transformer is reconnected to repeat its operation from higher main taps on the main transformer. Also there have been tried variations of European schemes, utilizing a motor-driven switching device which shifts taps under zero voltage conditions obtained by mechanical interlocking with arcing switches designed to handle the arcing duty.

Since the year 1937 improvements in the basic type of voltage control have been evolved which have consisted essentially of improvements in the contactors themselves, in the interlocks which are used to insure against faulty closure of switches, and further in an arrangement of auxiliary relays known as "sequence or interlocking" relays which, while having increased the number of operating coils in the system, have materially decreased the number of contacts in the control circuits and have given an overall improvement in reliability and a decrease in maintenance.[3]

One of the chief sources of trouble that arises with notching schemes using individual contactors is the failure of one of the individual contactors to open its circuit when it is called upon to do so. This may arise from purely mechanical reasons such as sticking of the operating rod or some of the mechanical portions of the contactor, or from electrical reasons, such as those which cause the tips of the contactor to weld together. Because of the relatively large number of tapping contactors used upon a modern locomotive (24 in the case of the latest New Haven and Pennsylvania Railroad locomotives), the number of interlocks required for complete protection against contactor closure when a given contactor has stuck closed for some reason was prohibitive. For this reason previous to 1937 it was considered sufficient to interlock positively against direct short circuits upon a given preventive-coil bus, and no attempt was made to prevent possibilities of overvoltage being applied to a preventive coil.

The development of the "sequence relay" made interlocking possible which would prevent the closure of any switch that might set up undesirable conditions after another had stuck closed.

To protect against an unbalanced preventive coil, caused by failure of a switch to close in sequence, differentially connected current transformers supplying a thermal-element preventive-coil relay are provided. The relay characteristics are so proportioned that on normal switching operations, in which one tap switch is opened before the next is closed, when the preventive coil is left connected with but one leg for a few cycles, the relay will not trip. Should a tap switch remain open, the heater element will cause the relay to trip after a definite time, opening the control circuits to all the tap switches. Such thermal relay connections also provide protection against internal failures of the small preventive coils, as such faults give rise to current in the same direction as exciting currents and thus are effective in tripping the thermal element.

Operating experience prior to 1937 developed the weakness of utilizing the three possible unbalanced preventive-coil combinations as the first three starting notches for a locomotive. Locomotives so connected gave rise to an abnormal number of preventive-coil failures directly traceable to operation on one of the unbalanced notches while starting heavy trains at difficult locations. Modern practice therefore prescribes the use of balanced connections for the coils for all notches—except possibly the first—

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where currents are low, and there is no occasion for extended operation.

The aforementioned improvements, however, do not progress greatly toward the solution of one of the first criticisms of the a-c locomotive, namely, the sag in tractive effort that occurs between notches. During the transfer from one notch to the next it is necessary that one end of a preventive coil be open-circuited completely before closing it in on the next higher voltage. During this time the total load current for the particular preventive coil is carried through one half of its winding. This winding offers a considerable impedance to the load current because of the unbalanced ampere turns in the coil. The impedance drop under these conditions becomes the impedance that will be supported by the iron plus the series-air-core impedance of the turns in the coil itself. As used here, "series-air-core impedance" refers to the reactance of the coil, assuming no iron is present, as the ampere turns available are many times in excess of those required to saturate the iron.

The insertion of the high impedance of one half of a preventive coil in the circuit causes a very marked decrease in the voltage left to be applied to the traction motors, with the result that there is a considerable falling off of traction motor current, and thus a sag occurs in the motor tractive effort. Under severe conditions of starting and running when operating at tractive efforts very close to the slipping point of the wheels, such a reaction during the notching is very undesirable. Most of the control schemes tried out or proposed have had as one of their main objectives the smoothing out of the notching characteristics between notches. Some of the schemes have been more or less successful in this, but for the most part they have introduced other undesirable features.

Another characteristic inherent in the three-preventive-coil scheme is the presence of the extremely high voltages which occur in the saturated preventive coil undergoing tap change. Such voltages are of the "peaked-wave" variety, maintaining for only a very small portion of each cycle and occurring when the current wave passes through zero. At the higher transformer voltages and motor currents the "peaked-wave" voltages have been measured which reach values of approximately twice the transformer secondary voltage. This comes about from the fact that all of the available voltage of the transformer secondary may appear across one half of the small preventive coil for an instant during each cycle, and the turn ratio of the preventive coil will give twice this voltage between its two outside terminals. When it is considered that the nominal rated voltage of a small preventive coil is of the order of 128 volts, and the secondary voltage of the main transformer may be of the order of 1,400 volts, the amount of overvoltage that is applied to a preventive coil is extreme.

The presence of peak voltages during switching operation imposes a very severe switching duty upon the tap switches, as is evidenced by the loud noise and substantial arcing that usually occurs during operation of the tap switches under load conditions.

The saturation of the preventive coil during the transition period has another effect which at times in the past has been the most important phenomenon in connection with the switching. This is the occurrence of a displaced current wave upon the closure of the next higher tap switch with the result that very high values of transient currents are obtained. If the value of air-core reactance in the preventive coil undergoing switching is not of sufficient magnitude, currents high enough to cause welding of the tap switch may occur.

These extremely high currents come from:

1. Trapped flux in the coil being switched due to the reversal of applied voltage. This phenomena is similar to that which sometimes occurs when a power transformer is energized and the switch closure comes when the instantaneous applied voltage does not correspond to the flux in the transformer iron, with the result that a distinct "bump" can be heard if one is in the immediate vicinity of the transformer.

2. A component from the trapped flux of the large preventive coil which may be saturated, and many times is, during the switching operation.

3. The proportionate share of the load current for the particular switch involved.

Such currents do not occur every time a transition is made, as their occurrence is dependent upon the instant during the

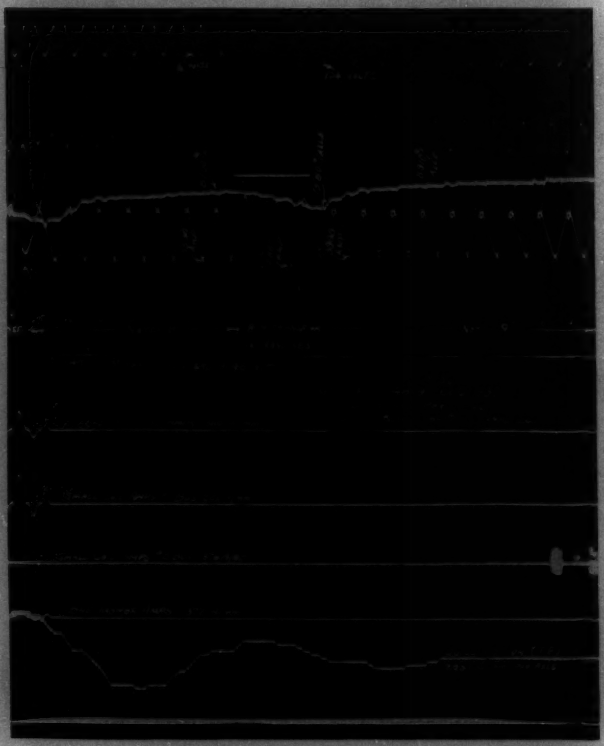


Figure 1. Film 52—transition between notches 8 and 9 without transition resistor

current wave that the tap switch is closed. For this reason tests designed to record the maximum values of current obtained upon contactor closure have to be made recording the results of very large numbers of closures.

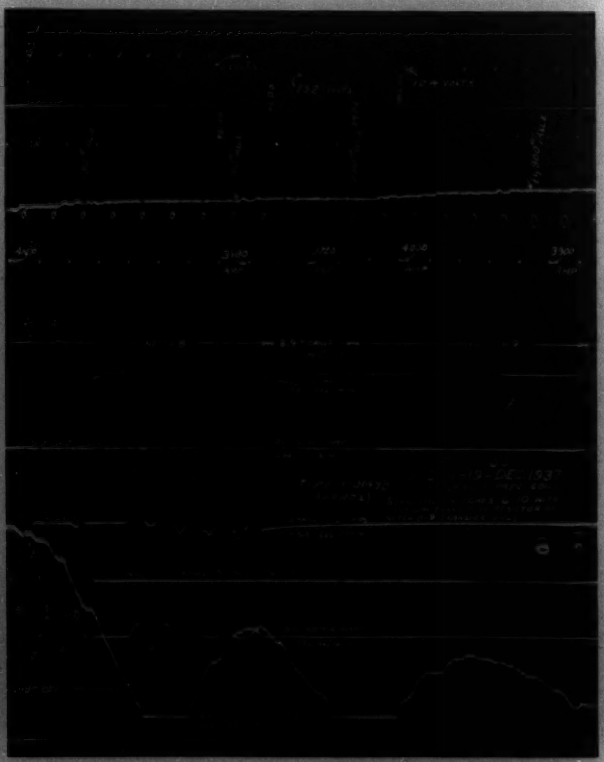
The surge current peaks have been measured as high as 23,000 amperes in a 1,250-ampere contactor, and possible values may be calculated with a reasonable degree of accuracy. Preventive-coil air-core reactances are usually figured to limit these currents to around 12,000 to 14,000 amperes, which seems to be a satisfactory value for the circuits and contactors involved.

Most of the early difficulties with the three-preventive-coil scheme of control centered around the welding of the tap-switch contacts, as then it was not known what magnitude in surge currents would be obtained, nor what steps would have to be taken to limit these currents to satisfactory values.

One of the suggestions made during the early days involved the connection of a resistor across the preventive coil to prevent the extreme amount of saturation which occurs in the coil. However, this suggestion was not followed up as it appeared simpler and more helpful to connect special air-core reactances in series with the preventive-coil bus circuit to limit the flow of exciting current through the small preventive coils. While the air-core reactance coils were so connected as to limit the flow of exciting current, the arrangement was such that the effect of load currents was to balance out the reactances of the coils. In later designs the reactance of the external coils was built into the preventive coils themselves so that the extra pieces of equipment are no longer required.

In 1937, during the search for a better scheme of control, it was suggested that a resistor of proper ohmic value be connected across the terminals of the preventive coil that was open-circuited during the transition. With this connection, while the preventive coil was operating "one-legged" the current would divide properly and flow through the resistor to the preventive coil and then to the motors. The value of resistance was determined by the maximum current to be encountered in the service of the locomotive and the designed voltage of the preventive coil. The voltage across the preventive coil at no time then would exceed its maximum designed value, and there would be no possibility of saturation of the coils.

Figure 2. Film 53—transition between notches 8 and 9 with transition resistor



Early Experiments With Transition Resistor

Such a scheme of connection was tried out upon the Pennsylvania Railroad in 1937, on locomotive 4819, at which time oscillograms were taken which showed very clearly the results to be expected from such an arrangement. In addition to the currents and voltages recorded on the films, it was also possible to measure directly the torque of the traction motors involved so that the results of the sag in tractive effort during ordinary notching and the lack of a sag in tractive effort in notching with the transition resistor were definitely recorded.

The drive from the traction motors to locomotive driving wheels is of the well-known spring cup type. In order to measure the motor torque, it was necessary only to provide an electric position-measuring device to indicate the deflection of the drive springs and record the indications on one of the oscillograph elements. When the spring constants are known, it is a simple matter thereafter to calibrate the indication of the element in pounds tractive effort.

The tests were confined to observing the effects on one transition only, namely from notch 8 to notch 9. The resistor used was of very small physical size, being capable of withstanding the currents involved for only a few cycles. The tests were all made at standstill, as it was impractical to measure the motor torque while the driving wheels of the locomotive were rotating.

The first of the oscillograph films (film 52) gives a record of the transition from notch 8 to notch 9 without the use of the resistor. Referring to film 52 (Figure 1) it will be observed that during the transition the tractive effort fell from 8,700 pounds per axle in notch 8 to 7,580 pounds per axle during the transition; the traction motor current fell from 3,530 peak amperes per motor to 2,880 peak amperes per motor and then rose again to 3,900 peak amperes per motor in notch 9 after

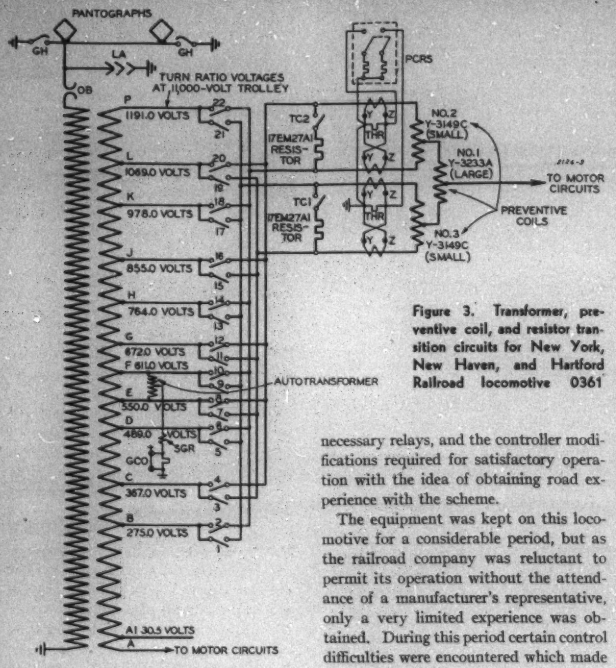


Figure 3. Transformer, preventive coil, and resistor transition circuits for New York, New Haven, and Hartford Railroad locomotive 0361

the transition was completed, this current corresponding to 8,910 pounds per axle as measured on the film. Also to be observed are the very high peaks in small preventive-coil voltage, which curve goes clear off the bottom edge of the film to a value impossible of determination. The rms value of the preventive-coil voltage for notch 8 is 43.5 volts, and for notch 9 is 49.8 volts.

Film 53 (Figure 2), taken immediately after film 52, with the transition resistor functioning, shows the very striking improvement obtained. In this case the tractive effort per axle moved gradually from 11,180 pounds per axle to 11,900 pounds per axle some time after the transition was complete. The increase in traction motor current was also gradual, raising from 3,680 peak amperes in notch 8 to 3,820 peak amperes during the transition, and then to 4,090 peak amperes after the transition was complete. The preventive-coil voltage is kept down to its normal value; the increase during the transition is only to 91 volts rms as compared with the nominal rating of the preventive coil of 128 volts.

Pennsylvania Railroad locomotive 4819 was subsequently equipped with a pair of resistors, a pair of resistor contactors, the necessary relays, and the controller modifications required for satisfactory operation with the idea of obtaining road experience with the scheme.

The equipment was kept on this locomotive for a considerable period, but as the railroad company was reluctant to permit its operation without the attendance of a manufacturer's representative, only a very limited experience was obtained. During this period certain control difficulties were encountered which made the scheme of getting the resistor switch closed before the tap switch opened, and then opening the resistor switch after the next higher tap switch had closed, somewhat unreliable. However, there was a noticeable improvement in locomotive acceleration and a very marked reduction in the amount of arcing on the tap switches, both in noise and the amount of visible arc, during the time the resistor transition equipment was working.

The equipment was subsequently removed from Pennsylvania Railroad locomotive 4819, and returned to the manufacturer's plant for reconditioning.

Service Experience on New York, New Haven, and Hartford Railroad

Having observed the performance of Pennsylvania Railroad locomotive 4819 with the resistor transition equipment functioning, New Haven representatives expressed interest and a desire to have the equipment turned over to them for use and service experience on one of their locomotives, in order to explore fully the possibilities of improved locomotive performance and reduced tap-switch maintenance.

New Haven electric locomotive 0361 (Figure 6) was selected for the installation of the resistor transition apparatus. This locomotive is one of six built by the General Electric Company in 1938 and used in main-line passenger service between New York and New Haven. A brief description of the locomotive follows:

Class	0361–0366
Service	Passenger
Power supply	11,000 volts, 25 cycles, a-c, 666 volts, d-c
Wheel arrangement	2C+C2
Number and type of traction motor	6GEA-622
Total weight	432,000 pounds
Weight on drivers	273,000 pounds
Length between coupler pulling faces	77 feet 0 inches
Over-all width	10 feet 2 inches
Height over a-c pantographs down	14 feet 8 inches
Maximum tractive effort (25% adh.)	68,500 pounds
Continuous tractive effort	24,100 pounds
Speed at continuous tractive effort	56.0 miles per hour
Continuous rated horsepower	3,600
Photograph	Figure 6

This locomotive has 22 tapping contactors and 20 a-c controller notches without intermediate buck-boost notches. No sequence relay interlocking is provided.

The application was made while the locomotive was in the shop for its first truck overhaul and traction-motor commutator turning after making a total mileage of 263,000. It was released from the shop July 16, 1941, after making various yard tests to determine that the new apparatus was functioning properly. Before assignment to any revenue trains, however, it was given a series of light runs on the main line, still further to insure that operation was correct.

In order to find out if duty on the tapping contactors was actually lessened by reason of the elimination of severe current and voltage transients in the preventive coils, new tips and arc chutes were installed on all such contactors. On subsequent periodic inspections burning and wear of tips and arc-chute sides could be compared with conditions on similar locomotives without the resistor transition.

The transformer and preventive coil connections for this locomotive are as shown in Figure 3. The control circuits in Figure 4 show the master controller and the relay circuits associated with the operation of the resistor transition switches *TC*1 and *TC*2. Figure 5 is a sequence diagram for the operation of the relays, tap switches, and resistor transition contactors for certain representative steps The following is a brief description of the operation of the control circuits which have as their function the closure of the resistor transition switch before the opening tap switch breaks its

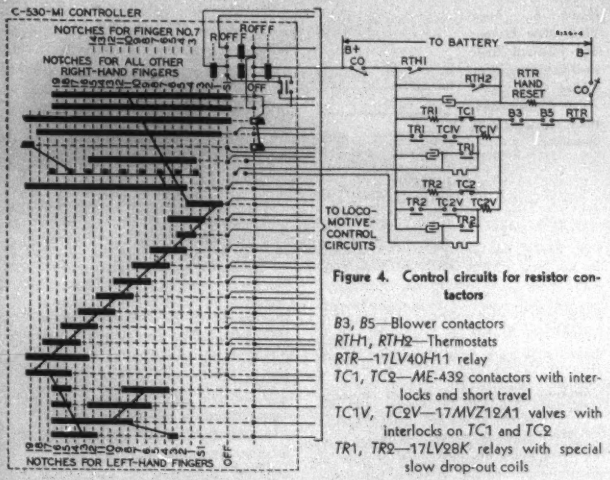


Figure 4. Control circuits for resistor contactors

B3, B5—Blower contactors
RTH1, RTH2—Thermostats
RTR—17*LV*40*H*11 relay
TC1, TC2—*ME*-432 contactors with interlocks and short travel
TC1V, TC2V—17*MVZ*12*A*1 valves with interlocks on *TC1* and *TC2*
TR1, TR2—17*LV*28*K* relays with special slow drop-out coils

contacts, and thereafter the holding of the resistor transition switch closed until the next tap switch is closed.

Upon the movement of the master controller from one notch to the next, a segment between notches gives an impulse of electric energy to an appropriate wire which is connected to the magnet valve of the resistor transition switch it is desired to close. The operating coil of the magnet valve is wound for approximately half the normal control voltage of the system so that its operation will be very fast. The coil is protected against the control voltage, should the controller be left midway between notches, by a resistor that is shorted out of the circuit by a relay (*TR*1 or *TR*2), whose circuits are made up before the transition is initiated, as described later. Should the controller remain between notches, the relay is de-energized by interlocks on the resistor switches, thereby inserting the protective resistance in series with the magnet valve coil. Attached to the armature of the magnet valve is an auxiliary normally open contact (*TC1V*, *TC2V*) which "makes" upon the initial travel of the armature before the latter starts to open the air valve. This contact forms a holding circuit from the battery to cause the magnet valve to continue to close, thus operating the air valve and supplying air to the cylinder of the contactor, regardless of the length of time the impulse remains on the wire from the controller. The transition switch closing its main contacts also opens the circuit to the transition relay by means of interlocks. Another set of transition relay contacts (*TR*1, *TR*2) are in series with the holding circuit to the magnet valve of the particular switch involved. The transition relay has a time delay built into it of sufficient duration to keep its contacts closed until enough time has elapsed for the transition of the main tap switches to have been completed. At the end of the prescribed time the transition relay operates, opening the holding circuit and causing the transition contactor to open. The interlocks on the transition contactor (*TC*1, *TC*2) again make up the circuit to the transition relay, which again "picks up" and is then ready for a repetition of the same cycle when it is initiated by an impulse from the master controller. There are two sets of relay equipments, one for each transition resistor.

The resistors are located over the exhaust air stream from the radiator of the main transformer, and the control is so interlocked with the blowers that it will not operate unless the blowers are running. As another safety factor a thermostat has been placed over each resistor so that, when they exceed a safe temperature, the thermostat will close, energizing the thermostat relay (*RTR*) which latches in its energized position and de-energizes the resistor transition circuits. The resistor transition equipment cannot then be operated until the resistor has cooled, and the thermostat relay has been reset by hand. The resistor thermostats are in the nature of "backup" protection, as the resistors themselves have been designed liberally enough so that, with the aid of the ventilation from the transformer radiator, it would be permissible to let them stay on the preventive-coil bus energized continuously without damage to themselves. They have a very high temperature coefficient of resistance so that, as they heat up, they inherently reduce the current flowing through them. However, in order to protect the adjacent equipment and cab structure from excessive heat, it was considered desirable to add the thermostat to each resistor.

The resistor transition switches are standard tap switches equipped with a reduced tip gap to obtain short travel and space filler to reduce the surplus volume in the cylinder. Minimizing the clearance volume of the cylinder reduces the volume of air required to start the switch moving, and reducing the switch travel cuts down the time required for closure. These refinements in the switch, combined with a magnet valve that is operated on approximately twice normal voltage, suffice to give a switch with the required operating speed.

This arrangement of the control circuits appears to have been eminently satisfactory, and where the segments in the master controller have been properly aligned so that the impulse to the magnet valve is started before its corresponding tap switch has been de-energized, no difficulty has arisen in insuring that the resistor switch is closed before the tap switch breaks its contacts. In normal notching the duration of the impulse from the master controller is of the order of $^1/_{100}$ of a second.

When the trial of resistor transition on a New Haven electric locomotive was first considered, two trains immediately came to mind as offering the best chance to observe the effects. These two trains were exceptionally heavy morning and night

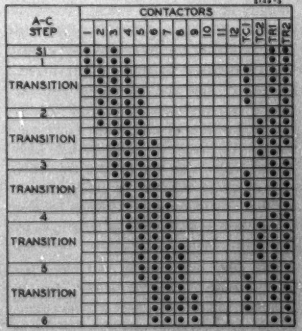


Figure 5. Sequence diagram for representative notch transitions with transition resistors

commuter trains operating as local expresses between New York and New Haven; each required higher locomotive output than any other passenger train handled electrically. The electric locomotives regularly assigned were the 0361–0366 class. Short-time load demands, when operating the two trains in question, reach a peak of 7,600 horsepower, more than twice the continuous rating. These peak demands come about through frequent stops on a fast schedule for half of the run in each direction.

These two trains therefore were selected for the initial test runs. Other trains were handled as the locomotive was used in the regular 0361–0366 pool.

Two results of the resistor transition were immediately apparent. One was the virtual elimination of the usual barking of contactors on heavy current during acceleration. The second was the smoothing out of the tractive effort increments on acceleration, resulting in less tendency for the locomotive drivers to slip. This was remarked upon almost immediately by those operating the locomotive.

At first, the resistor transition apparatus was cut out except when a road foreman or others familiar with the equipment were riding the locomotive. In a short time, however, it became apparent that it could satisfactorily be left cut in, depending in the event of trouble on the thermostats or the instructions issued to the crews for cutting it out. The latter was a simple process, involving only the opening of a small double pole, single-throw control knife switch which made the transition contactors inoperative and returned the locomotive to normal operation.

Experience in regular operation since this time has developed practically no trouble, and the equipment has been continually in service and cut in, except for several instances of thermal relays tripping, probably due to enginemen operating in between notches on the master controller, and one period of approximately two weeks due to an error in judging the position of the timing relay contacts. The eight months of use have demonstrated that the resistor transition equipment is reliable in its operation without any more attention than is given other electric apparatus on the locomotive.

The duty on tapping contactors has been lessened. Unfortunately, due to operating conditions, there was no opportunity to determine quantitatively how much benefit was obtained, but qualitatively much benefit was observable. This means that aside from the operating advantages already described, there was a reduction in maintenance of tapping contactors, which is an important item on a-c electric locomotives. Against this, however, must be placed the additional maintenance of the resistor transition equipment, particularly the contactors and the segments and fingers on the master controllers.

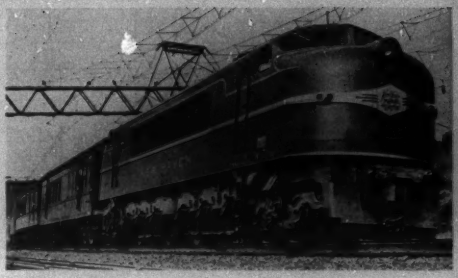


Figure 6. New York, New Haven, and Hartford Railroad Company locomotive 0361 upon which resistor transition equipment is operating

Another feature of the equipment is that a certain amount of care must be taken by the engineman when operating the controller. The control-circuit scheme is based on a train of events initiated by an impulse from the controller, and subsequent impulses must be spaced far enough apart in time so that the initial train of events has been completed, or else the most desirable operation is not obtained. When accelerating from standstill, a short pause normally occurs between each two notches, and the operation is always correct, but in notching on or off too fast when up to speed, the resistor transition may be only partly effective because of lack of time between notches. This is only of interest from the standpoint of duty on preventive coils and tapping contactors; tractive effort considerations are not critical under these conditions.

Conclusions

While the resistor transition equipment was applied to a New Haven passenger locomotive as representing one of the latest type of a-c locomotives in service, it would seem that the application would find its greatest usefulness in freight locomotives where smooth-starting tractive-effort characteristics are practically a necessity, and where starting duty is both prolonged and severe.

In general, the resistor transition scheme, developed and applied as described, has given gratifying results in its apparent improvement in the acceleration of the locomotives to which it has been applied, through the eduction in the arcing duty on the tap switches as evidenced by the almost complete lack of any arc noise and the very much smoother operation of the locomotive when notching.

Although the resistor transition has a beneficial effect on tap-switch surges after closure of the higher tap switch during a transition, because of the fact that it will prevent saturation, particularly of the large preventive coil, it is still necessary to analyze carefully each case to insure that excessive tap-switch surges are not obtained with the given values of series air-core reactance in the small coils. The fact that the transition resistor is still energized after the next higher tap switch has closed means that the current flowing through the resistor is superimposed upon the small preventive-coil exciting current, with the result that the surge current may actually not be greatly different from what it would have been, had a resistor not been connected to the circuit. However, with some combinations of equipment, the presence of the resistor will result in a definite reduction in the surge, and each case must therefore be analyzed on the basis of its own merits.

A further study of the scheme and its application would seem to be warranted for heavy duty a-c freight and passenger locomotives.

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Electric Equipment for Large Electrochemical Installations

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Synopsis: The increased demand for aluminum, magnesium, chlorine, copper, and zinc for war purposes has made the electrolytic processes for these materials the largest consumers of electric energy in this country.

The most frequently encountered d-c and voltage requirements of these four principal electrolytic processes are discussed. An illustrative current-time and voltage-time characteristic curve for starting a chlorine cell line is shown, and the requirements that such characteristics impose on the electric equipment are discussed. The current-voltage characteristics of aluminum, magnesium, chlorine, and zinc cell lines are also shown.

A typical installation of conversion equipment for an electrolytic process plant is given, and the reasons for selecting the particular types of electric equipment and its physical and electrical arrangement are discussed.

As part of this discussion, there are included characteristic curves of rectifiers showing the effect of ignition control on power factor for 6-, 12-, and 36-phase combinations. A table giving a "rule-of-thumb" relationship between the number of phases and kilowatt limits which have been found in practice to provide operation reasonably free from telephone interference is included. There is also given a tabulation of phase shifter combinations, by means of which multiphase operation can be obtained with various combinations of standard six-phase rectifier transformers.

THE electrochemical industry has very recently become one of the most important consumers of electric energy in the United States with increasing production of aluminum and magnesium and, in the near future, will become an even more important user. The "Big Four" of the electrochemical industry—aluminum, magnesium, chlorine, and the sister metals, copper and zinc—have now installed over 2,500,000 kw of conversion apparatus of all types in this country, and the end of the year 1942 will see an additional million kilowatts installed in these four branches of the electrochemical industry.

This conversion equipment operates at almost 100 per cent load factor and converts power at a yearly rate of 25,000,000,000 kilowatt-hours, or nearly one quarter of the total energy used for all industrial purposes. This percentage may at the end of this year well increase to perhaps 40 per cent of the total industrial power.

There are many other electrochemical processes of less importance. Perhaps the next largest in installed conversion capacity produces fused sodium chloride with approximately 60,000 kw. Following this in importance are processes for production of hydrogen, manganese, potassium perchlorate and sodium chlorate, and other similar processes. The application problems are similar to those of the four major industries.

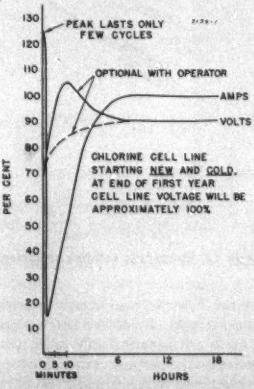

Figure 1. Chlorine cell-line characteristic

While these figures include conversion apparatus of all types (rectifiers, rotary converters, and motor generator sets), the rectifier is now the prevalent choice of the industry for converting such large amounts of power into direct current. Since 1937 very few large electrolytic installations using rotating conversion equipment were made in this country or in central Europe. During the last two or three years, the ignitron-type rectifier has been chosen for most of the installations in this country, although the multi-anode type of rectifier is still the choice of foreign designers.

The application engineer dealing with the electrochemical industry is at a certain disadvantage compared with application engineers for other industries, inasmuch as the chemical industry has published very little data concerning their electrical requirements. This may be attributed to the fact that electrochemical processes and techniques are often of a highly secret nature, not only in time of war, but also under peacetime conditions when the process is a matter of competitive endeavor. The electrical-application engineers would welcome more complete and precise knowledge of the electrical characteristics of the various electrolytic cells, presented not from the point of view of the chemist, but from the point of view of the electrical engineer. A few typical characteristics are discussed below, but this subject needs considerably more analysis.

Electrochemical Process Characteristics

Aluminum

A typical electrolytic cell line or "pot" line for the production of aluminum consists of a number of cells connected in series and is supplied with a normal direct current of 60,000 amperes at perhaps 650 volts. Such a line may require very little adjustment in d-c voltage except for minor variations of cell resistance and of the counter electromotive force of the cells. Adjustable voltage is however required, if the number of cells is decreased below normal, or for baking out a new or "green" cell line. The variation of the a-c supply voltage may require means of maintaining pot-line current and voltage at a constant value. Means for accomplishing such voltage regulation will be discussed later. Under ordinary operating conditions, after such a line is once put into operation, it will run for months or even years, with a voltage and current variation of not more than five or ten per cent.

Another typical aluminum cell line with cells of the so-called Soderberg type has a normal capacity of 32,000 amperes at 650 volts. With this type of cell more frequent adjustment in the d-c voltage is found very useful for the purpose of starting "green" cells or baking out cell linings.

Magnesium

As far as the application of the electrical conversion equipment is concerned, a magnesium cell-line is very similar to the

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aluminum line. The magnesium cell line may have a normal d-c rating of 60,000 amperes at 600 volts, although a large installation is now in the process of erection which, based on European practice, will use a large number of 20,000-ampere 350-volt cell lines. Another installation is using 32,000-ampere 600-volt lines.

Wider adjustment in the d-c voltage is required on a magnesium cell line as compared with one for aluminum, because a new cell line is usually started with only a few cells and is built up over a period of several weeks by adding new cells in series. Both in this country and abroad, installations have been made with a wide range of adjustable d-c voltage, even though normal operation is at practically constant voltage.

Chlorine

Typical chlorine cell lines use from 7,500 to 10,000 amperes at 500 to 700 volts, depending upon the type of cell used or the number of cells connected in series. Some cells are designed for 1,800 to 2,000 amperes, and four or five of these may be connected in parallel on a common d-c bus. Usually each 7,500- or 10,000-ampere cell line is supplied from one rectifier unit, without interconnection with other cell lines on the d-c side except in case of emergency. This arrangement provides flexibility to meet the day-to-day variations in cell-line requirements. Such lines are operated at essentially constant d-c voltage. Figure 1 shows typical voltage- and current-time curves for a chlorine line which is placed into operation for the first time.

It should be pointed out that these curves are not based on tests, as the authors might desire, but on previously published information and on theoretical considerations.

The Figure 1 shows an initial instantaneous peak rising to perhaps 125 per cent after the cell line is first thrown on full voltage and before the counter electromotive force or battery action of the cell is established, a phenomenon which happens within a few cycles. The sodium-chloride solution initially has a high resistance, while it is cold and dilute. For the next six or eight hours the current rises as the resistance decreases with increasing concentration of the solution.

The initial voltage reduction to 60 or 70 per cent required of the conversion equipment to keep down the initial inrush of current is well within the capability of ignition control of a rectifier. Minor adjustments in the voltage required from day to day are also usually made by means of ignition control. Larger d-c voltage changes may be obtained with taps on the rectifier transformer as will be discussed later.

It should be noted that the characteristics of the individual cells are somewhat obscured if a number of lines are operated in parallel.

Copper and Zinc

A typical copper or zinc cell line is quite different from the chlorine line as regards the conversion equipment. A zinc line may require about 10,000 amperes at 500 to 600 volts, depending on the number of cells connected in series. Foreign installations have been made using voltages up to 800 or 850 volts. For normal operation the cell line is operated at substantially constant d-c voltage. Usual applications require some transformer taps for d-c voltage adjustment on a cell line as the number of cells in series are changed.

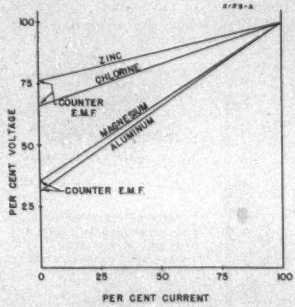

Figure 2. Electrolytic cell-line characteristic

Since, however, the electrolytic production of copper or zinc is a batch process, where a cell is periodically taken out of service for the purpose of stripping copper or zinc from the electrodes, the cell-line voltage must at the same time be lowered to such a low value that the disconnection of one cell may be made at slightly above zero current. The voltage reduction required to accomplish this is approximately 25 per cent, usually obtained by ignition retard.

Figure 2 shows a typical voltage-current characteristic of a zinc line. It is easily understood that the removal of one cell from the circuit by means of short-circuiting this cell should, from the standpoint of operation, be done as quickly as possible in order to revert to full current and full production without too much loss of time.

It is important that some cell current be maintained, at least at a low value, at all times to prevent the copper or zinc already deposited from going back into solution.

Figure 2 also shows cell-line characteristics for other cell lines. Chlorine has a counter electromotive force of approximately 66 per cent. For alumina dissolved in cryolite, the authors estimate a counter electromotive force of about 30 per cent based on the theoretical voltage of dissociation of 1.38 volts per cell and the approximate total voltage drop of 5.9 volts per cell. The counter electromotive force of fused magnesium chloride based on similar data is shown to be approximately 35 per cent. The authors have no accurate data on the length of time for which this counter electromotive force persists after an interruption in the current supply.

Some cell lines have their mid-point grounded through a resistor for the purpose of lowering the cell potential to ground. Such installations usually have a relay and alarm system in the ground connection to notify the operator of accidental grounds on the cell circuit. Grounding the mid-point of the cell line seems to be common practice abroad but is only occasionally used in this country. The disadvantages of its use are slightly more electrical losses to ground because of current bypassing some cells.

Selection of Electric Equipment for Electrochemical Processes

Rectifiers Versus Rotating Apparatus

The mercury-arc rectifier has become so well established in the electrochemical field that it is hardly necessary to dwell at great lengths on the advantages it has over rotating apparatus. However, it is desirable to review very briefly some of these advantages.

The space requirements for the installation of rectifiers are quite moderate, and no reinforced foundations are needed such as are required for rotating apparatus.

In the larger units at 600 volts direct current, the rectifier-conversion equipment may be installed for approximately $35 to $40 per kw. This includes the incoming 13.8 kv 60-cycle a-c switchgear, autotransformers, rectifier apparatus, cable and copper bus bars for the main d-c bus, building, and installation labor. This approximate installation cost figure would cover a layout as shown in Figures 5A and 5B.

An especially important consideration in wartime is the fact that the amount of particularly scarce materials, such as copper and steel, is considerably less in a

rectifier installation than in rotating apparatus. Incidentally, it is for this reason that the rectifiers have for some time been more widely used in Europe than they have been in this country.

The efficiency of the modern ignitron-rectifier equipment in the voltage range around 600 volts is in excess of 95 per cent, including the transformer losses and the power consumed by the rectifier auxiliary equipment, such as pumps and ignition apparatus.

The efficiency of the conversion equipment is of special importance in the electrochemical industry, because these processes operate at close to unity load factor, and the electric energy which the conversion equipment supplies over a year's time may cost as much or more than the cost of the conversion equipment itself.

An operating advantage of the rectifier installation over a rotating-apparatus installation is particularly emphasized by

Table I. Phase Shifters Required for Multiphase Operation

Rectifier Transformers			
Number of 6-Phase Units	High-Voltage Connections	Phase-Shifting Auto-transformers Required	Number of Phases Operation
1	Delta or wye	None	6
2	1 delta, 1 wye	None	12
3	2 delta, 1 wye	2 10-degree	18
4	2 delta, 2 wye	2 15-degree	24
5	3 delta, 2 wye	2 12-degree, 2 6-degree	30
6	3 delta, 3 wye	4 10-degree	36
7	4 delta, 3 wye	2 4.29-degree, 2 8.57-degree, 2 12.86-degree	42
8	4 delta, 4 wye	2 15-degree, 4 7½-degree	48

the problem of restarting a large-capacity cell line after a complete power failure or shutdown. Assuming that such a cell line is supplied from six 10,000-ampere rotary converters, it is necessary after a power failure to restart and resynchronize all of the rotary converters with the d-c breakers open. Since it is impossible to close all of the d-c breakers simultaneously, one of the rotary converters will assume the entire load, its breaker will trip off on overload, and succeeding breakers will follow.

To meet this problem with rotary converters, a large cell-line breaker is resorted to, which may be rated 60,000 amperes continuously. By using this rather unwieldy device, all of the rotary converters may be paralleled on the d-c bus with this cell-line breaker open and then the breaker closed.

A rectifier application easily circumvents this problem. With rectifiers, all d-c and a-c breakers are closed with the ignition circuit de-energized. The potroom load is picked up by energizing the ignition circuits of all rectifiers simultaneously. No cell-line breaker is needed. It is obvious that the time element, in re-establishing service after a power interruption, is very small indeed for a rectifier station as compared with a rotary converter installation.

Rectifiers provide a certain amount of d-c voltage adjustment by means of ignition retard, which allows quick and easy compensation for changes in the a-c supply voltage or for changes in the cell-line conditions; whereas with rotary converters, the use of boosters must be resorted to. It should be pointed out, however, that the continuous use of ignition control is not resorted to in practice beyond four or five per cent, since a wider use is accompanied by lowering of the power factor and an increase in the tendency of the rectifier to arc back.

All in all, it may be fairly stated that the many advantages of rectifiers over rotating apparatus makes their selection for a large electrochemical installation a foregone conclusion.

A considerable advance in the art of rectifier design is represented by the single-anode rectifier tank. As illustrated in Figure 3, these single-anode tanks or ignitrons are assembled in groups of 12 to supply 5,000 cathode amperes. This ignitron design has resulted in an increase of efficiency by a reduction of the arc drop to 20 volts or less; which, for such installations, means an over-all efficiency of about 95 per cent. The lower arc drop and the high efficiency result from the fact that the anode encased in a single tank can be placed closer to the mercury-pool cathode.

Because each anode is confined in a relatively small tank compared to the large multianode arrangement, with the ignitron it is possible to make much tighter vacuum seals, and therefore better to maintain the vacuum. Furthermore, if a tank leaks, or trouble develops with one tank, it is a relatively simple matter to replace this tank, whereas it is much more serious when a large multianode tank has to be taken out of service. For these reasons the single-anode ignitron rectifier is now the choice of the electrochemical industry, foreign countries excepted.

Figure 3. Large rectifier substation

Selection of Rectifiers

Figure 4 shows the general arrangement of an electric system for three 60,000-ampere 600-volt electrolytic cell lines. While this sketch does not represent in detail an actual installation, nevertheless all of the features shown are commonly installed, and the sketch will serve as a basis for discussion of the various reasons why the equipment shown was selected.

Each 60,000-ampere cell line operates as a unit. Therefore, the largest available size rectifier units are chosen, in order to obtain maximum economy in first cost. The rectifier transformers are selected so as to supply two rectifier units from one transformer, or a total of 10,000 d-c cathode amperes. This is about the upper limit. The maximum of 10,000 cathode amperes d-c per rectifier transformer has been found both in this coun-

try and abroad to be a conservative upper limit because of large copper sizes to be handled, stresses in the transformer during arc-back, and for other design reasons. Thus the logical choice of rectifier units for this case is the 5,000-ampere, 12-anode ignitron, similar to those shown in Figure 3.

In view of its relative simplicity of design and sturdiness of construction, the six-phase double-wye or quadruple-wye secondary connection is most widely used, both here and in foreign countries. Some 12-phase rectifier transformers have, of course, been used for small installations. As shown on Figure 4, the transformer selected has quadruple-wye secondary connections. Two wye, with their interphase winding, supply one 5,000-ampere rectifier, and two duplicate wye, with interphase winding, supply the other rectifier.

Number of Phases

As the six-phase, 10,000-ampere cathode d-c rectifier transformer is selected, there are now required six such units to supply the 60,000-ampere pot line. This is a total of 36,000 d-c kw. Investigations of rectifier wave shape and its influence on telephone communications indicate that the telephone influence is, to a very large extent, dependent on the characteristics and the total installed capacity of the a-c supply system, to which the rectifier installation is connected, and also on the number of phases selected. It has been fairly well established that such an amount of power operating at six phase would cause widespread telephone interference, if no coordinative measures are taken. Therefore, the number of phases should be selected with reference to the ratio of the total rectifier capacity and the total system capacity supplying the rectifier installation.

Table II contains a "rule of thumb" of rectifier kilowatt ratings and number of phases selected for 60-cycle rectifier operation. This table is, of course, subject to interpretation and should be used with extreme caution, since, for instance, there have been some cases of telephone interference caused by 200-kw rectifiers at the end of a long feeder. It is, however, generally applicable to rectifier installations on relatively large power systems; and so far as the authors know, there have been no cases of telephone interference caused by rectifiers in industrial plants within the limits shown in Table II.

The total kilowatts and the number of rectifier transformers on each pot line indicate in accordance with Tables I and II that the installation here discussed should use 36-phase relationship. Since there are six six-phase units, the rectifier tubes will fire in 36-phase relationship, if the primary voltages are shifted by ten degrees for each rectifier unit.

Table I gives a convenient reference for the number of phase shifters and the degree of phase shift required for combinations of six-phase transformers for multiphase operation. The use of 18-phase operation is inadvisable, because its principal harmonics are the 17th and 19th, having the greatest audio-sensitivity. The 36-phase relationship eliminates theoretically all harmonics below the 35th.

It has generally been found impractical to make sufficiently accurate estimates of the telephone influence in advance of a rectifier installation, because of the many variables and unknowns, which allow only approximate estimates of the telephone influence. Therefore, it has become the practice, supported by experience, to evaluate only approximately the telephone influence and choose the number of phases in some such "rule-of-thumb" fashion as shown in Table II.

If it should ever become necessary in a specific case, remedies such as increasing the number of phases or a-c line filters can be applied after the installation has been made.

It should be clearly borne in mind that the foregoing discussion refers to a 60-cycle supply. Since telephone influence is sensitive to certain harmonics, Table II does not apply to 25-cycle systems. An installation with the same number of kilowatts should have a little over double the number of phases for a 25-cycle system as it has for a 60-cycle system.

In addition to the reduction in telephone influence, the multiphase operation offers definite economic advantages, since the increase in the number of phases improves the power factor as indicated in Figure 6. This figure is based on design data of an actual installation whose basic unit is the six-phase transformer. It can be seen that when the number of phases is raised from 6 to 36, the power factor improves from 92 to 95 at zero ignition retard. The increase in the number of phases also reduces the losses.

Instead of using basic six-phase transformer units, it is possible to use basic 12-phase transformer units. Such 12-phase transformers are much more commonly used in Europe than in this country, although they may be considered practical devices and have a definite field of application for smaller installations. All interphase transformers, indicated in Figure 4, are usually built in the common transformer tank.

The introduction of the phase-shifting autotransformer, as shown in Figure 4, results in some additional reactance in the circuit which would cause it to take slightly less load than a circuit without phase shifter. However, such unequal load distribution is easily compensated by a slight amount of ignition retard on the unit without phase shifter, and it is not considered necessary to insert any external reactance, although this is the practice in foreign countries.

The rating of rectifier transformers for

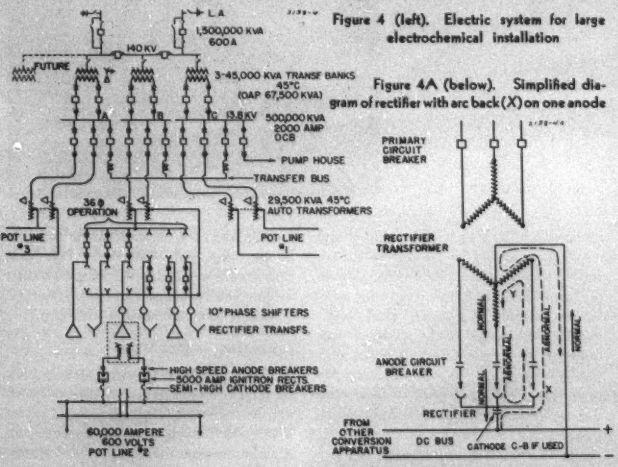

Figure 4 (left). Electric system for large electrochemical installation

Figure 4A (below). Simplified diagram of rectifier with arc back (X) on one anode

chemical installations is on a basis of 45 degrees centigrade temperature rise for continuous full load. This conservative rating for the transformers has universal acceptance in this country for electrochemical service, because the load factor is almost 100 per cent, and such installations may run for years under this full load condition. The 45 degrees centigrade temperature rise greatly reduces the maintenance on the oil and also provides some inherent spare capacity for emergencies, when it may be necessary to run the cell line on a reduced number of rectifiers, while one unit is undergoing maintenance.

With conservative design margins in both transformers and rectifiers, and with the high degree of reliability of modern rectifiers, such an installation as shown in Figure 4 would not normally require additional spare capacity. If the cell line is run with five instead of six units the overload is 20 per cent. It is generally practical, although not always desirable, to reduce the cell-line load while the single unit is off the line for maintenance. If it is essential to run the cell line with 100 per cent current at all times, a 10,000-ampere spare unit should be provided.

D-C Voltage Control

The installation illustrated by Figure 4 is assumed to require operation at d-c voltages as low as 100 for starting up a new cell line with only a few cells. Furthermore, the a-c voltage supply is assumed to vary five or six per cent from day to day, a condition which would cause the cell-line current to vary a slightly greater percentage. Both these conditions are frequently met in actual operation.

It is quite inadvisable to reduce the voltage from 600 down to 100 volts by ignition control. Figure 6 indicates that voltage reduction by ignition control, even as little as 16 per cent, reduces the power factor from 95 per cent to 82 per cent. Furthermore, operation of mercury-arc rectifiers with a large amount of ignition retard, for a long period of time, will increase the frequency of arc-backs. Experienced rectifier operators, therefore, use as little ignition retard as possible, and the application of ignition control should be limited to such cases where the voltage reduction is of only temporary character, as, for instance, when starting a cell line, where ignition retard of 30 to 40 per cent is permissible for a few minutes.

The other method of d-c voltage control, which uses a change of rectifier-transformer voltage, is not connected with these drawbacks. If only five or ten per cent change of d-c voltage is required over a long period of time, as would be the case for a chlorine line, this change should be obtained by taps in the rectifier-transformer high-voltage winding. These taps would be changed with the transformer de-energized, as such changes are sufficiently infrequent to make an interruption for this purpose acceptable.

However, with the change of d-c voltage required in the case of the installation here discussed, the only practical way of accomplishing this change of a-c voltage is through the use of an autotransformer with no-load taps. In this particular case the autotransformer would be supplied with seven no-load taps from 100 to 600 d-c volts rectifier output. Since these rather large changes in d-c voltage are required only once in several weeks, as a number of cells are added or removed from the circuit, changing these taps with the cell line de-energized imposes no serious hardship on the cell-room operator.

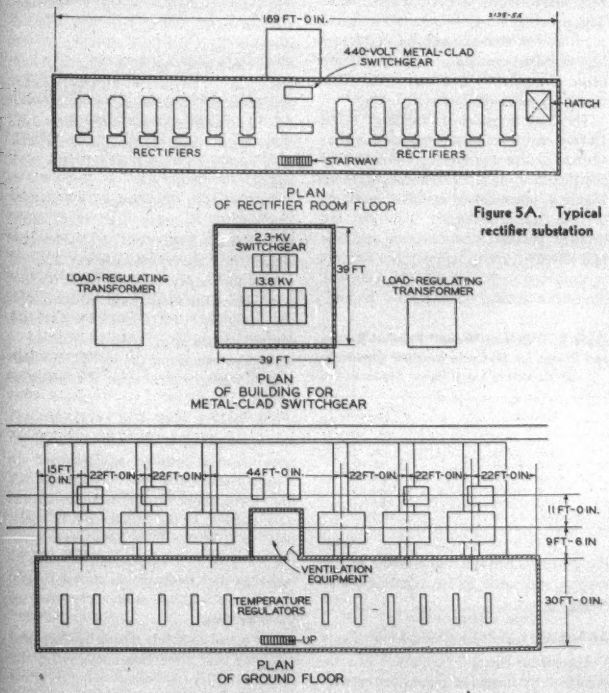

Figure 5A. Typical rectifier substation

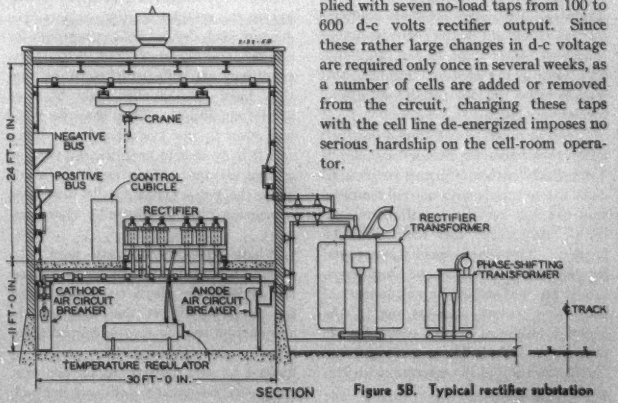

Figure 5B. Typical rectifier substation

In addition to the no-load taps, the autotransformer should in this case have load-ratio control to provide a plus or minus 60 d-c volts adjustment within the range of any of the seven taps of the no-load tap changer. This results in extremely flexible control and permits the operator to compensate for fluctuations in the incoming a-c power supply and also to bridge the gap between the no-load taps. The total range of 120 d-c volts load ratio control has been covered with 16 and 32 steps. Load-ratio control is also quite useful to the operator in maintaining constant cell-line current, as cell conditions change, and operators, who have this tool available, attest to its usefulness for this purpose.

The autotransformer with these features is also a tool for reducing the d-c voltage for the purpose of baking out a "green" cell line or for short-circuiting the d-c bus and simultaneously baking out all rectifier units themselves when they are first installed.

An exactly similar result can be obtained by the use of an induction voltage regulator when due attention is paid to the shifting of the primary voltage supply with respect to the ignition-system voltage. Induction voltage regulators are somewhat more expensive but are frequently used abroad.

With such flexible tools for voltage control available, it is not necessary to use any considerable amount of ignition control, except to balance the load between the various rectifier units.

The load-ratio control feature of the autotransformer makes possible automatic kilowatt input control for the pot line. This feature is not required by the cell-room operator, who will generally take all the kilowatts he can obtain, but by consideration of power contract formulas. By using constant kilowatt control, the load factor can be maintained at better than 98 per cent, and, with some power contract formulas, this feature alone will pay for the autotransformer very quickly.

It will be noted from Figure 4 that two autotransformers are chosen for each pot line. Each autotransformer is of sufficient size to supply with normal temperature rise four rectifier transformers and, in an emergency, five rectifier transformers. This spare capacity is required for reliability. When one autotransformer is out of service for maintenance of load-ratio control contacts, or in the event of failure of a cable connection to the main bus, the cell line can be operated for the duration of the emergency at five-sixths capacity.

Autotransformers, which are usually wye-connected, often have a tertiary stabilizing delta winding, as indicated in Figure 4. This tertiary winding will be of a certain minimum size as dictated by design consideration. If designed for a standard voltage commonly used to supply auxiliary plant load, the tertiary winding can be made to serve a double purpose. In a particular case, each tertiary winding was designed for 3,000 kva at 2,400 volts. This provides a very economical source of plant power, since no additional 13.8-kv high-voltage switching is required to make it available, and very little additional copper in the tertiary winding.

The autotransformer winding, being 13.8-kv wye-connected, provides a convenient means of grounding the neutral of the 13.8-kv system. While not shown by Figure 4, in an actual installation all six of the autotransformer neutrals are brought through disconnecting switches to a common grounding bus; and this bus is connected to ground through a current limiting resistor. Such neutral grounding greatly facilitates the relaying of the system and adds to its reliability and safety.

Table II. "Rule-of-Thumb" Kilowatt Ratings and Phases for 60-Cycle Rectifier Operation on Relatively Large Power Systems

Kilowatts	Phases
1,000– 2,000	6
2,000– 6,000	12
6,000–20,000	24
20,000–30,000	30
30,000–50,000	36
50,000 and up	48–72

Automatic Current Regulation

Automatic current regulation can be furnished by means of regulators operating on the rectifier ignition circuits. In general, such devices are not required for electrochemical installations, because the conditions are sufficiently constant, and they have been applied only to meet special conditions. They may be justified when the a-c system voltage varies, and it is desired to keep the d-c pot-line current constant. They are also of value where the rectifier must parallel with other conversion units of dissimilar characteristics.

Where such devices are used, the amount of ignition control is limited, and the undesirable effects on power factor are avoided. Where they are used in conjunction with load-ratio-control autotransformers, the ignition control is limited to perhaps five or six per cent range, and when these limits are reached, the load-ratio-control autotransformer taps are automatically changed by the regulator.

D-C Switchgear

High-speed d-c switching, particularly where more than one rectifier supplies the same load, is considered a highly desirable application requirement. By high-speed switching is meant a d-c circuit interrupting device which will begin to open in one-half cycle or less, and will therefore limit the peak current, and will completely interrupt it in approximately one cycle. The primary oil switch in the supply circuit to the rectifier transformer will have a normal operating time from six to eight cycles and would permit arc-back currents to reach undesirably high values.

Two methods of high-speed d-c switching are in common use: The older method uses a high-speed cathode breaker which trips on reverse current and removes the faulty rectifier from the d-c bus. Since the short circuit still exists on the secondary circuit of the rectifier transformer, it is necessary to attempt either to extinguish the arc in the rectifier by ignition blocking, or to open the main oil switch.

The second method of applying high-speed switching is the use of the high-speed anode breaker as indicated in Figure 4 and Figure 4A. The use of the high-speed anode breaker is an important development in the application of rectifiers, and, while there have been some papers written on this subject, the authors feel that it is desirable to review briefly the reasons for their wide acceptance by the operators.

The use of an anode circuit breaker provides the best protection not only for the rectifier but for the process being supplied by direct current, since its use gives a greater guarantee of continuity of service. The high-speed anode circuit breaker has one pole placed in each anode circuit and replaces a single-pole high-speed cathode breaker.

Referring to Figure 4A, normal current flow at a given moment is indicated by the solid-line arrows. When an arc-back occurs, one of the anodes (the right-hand one, not supposed to be carrying current at that instant) allows current to flow in the reverse direction. It will be seen that an arc back therefore causes two short circuits, one on the d-c bus indicated by the "abnormal" dotted arrow marked *X*, and the other on the a-c system indicated by the "abnormal" dotted arrow *Y*.

It is desirable to remove these short circuits quickly. An interrupter in the

anode circuits removes the short circuits from the a-c and the d-c systems simultaneously.

The high-speed anode circuit breaker opens in response to the reverse direction of current in the anode. The current peak is limited to one-half cycle or less and the current completely interrupted in approximately one cycle.

In comparison, the high-speed cathode circuit breaker would only interrupt the feedback from the d-c bus into the faulty anode, but some additional means has to be used to remove the short circuit from the a-c system, either by opening the primary oil circuit breaker or by attempting to suppress the arc in the rectifier by ignition control, while the use of the high-speed anode circuit breaker goes directly to the source of the trouble and quickly and promptly interrupts the anode circuit. It should be noted that the use of an anode circuit breaker is not a substitute for a primary oil circuit breaker, but only a supplement of it. Transformer fault protection and normal switching generally require the use of primary circuit breakers when such large transformer unit is connected to an a-c bus.

Some of the specific advantages of high-speed anode circuit breakers, particularly in those cases where more than one rectifier supplies a common d-c bus, are:

(*a*). The transformer is protected against the high currents which may result when a rectifier arcs back. Such high currents impose very severe stresses on the transformer.

(*b*). The other rectifiers are protected against supplying large d-c currents to the faulty rectifier. Such protection against heavy currents reduces materially the tendency for the normal rectifiers to arc back "sympathetically."

(*c*). The remaining normal anodes on the same rectifier are not called upon to supply heavy currents to the faulty anode, and their tendency to arc back, either immediately or in the future, is greatly reduced. Arc-backs beget arc-backs.

(*d*). The use of anode breakers, with high-speed reverse-current trip on each pole, greatly simplifies the protective control system. There are no additional relays nor wiring to go wrong.

(*e*). When one rectifier transformer supplies two rectifiers, as is usually the case in electrochemical work, the use of high-speed anode circuit breakers will remove one of them on arc-back and permit the other to continue in uninterrupted service.

The principle of the high-speed anode circuit breaker has been well proven in service. It is so fundamentally a correct device for the protection of mercury-arc rectifiers that future electrochemical application without them will be rare indeed.

It will be noted from Figures 4 and 4A that a semihigh-speed cathode breaker is indicated. These semihigh-speed cathode breakers provide overload protection in the forward direction, since high-speed anode breakers which trip on reverse current are not particularly well suited to trip on straight overloads in the normal direction. The semihigh-speed cathode-breaker overload trip is given a slight time delay to permit the breaker to stay in until the high-speed anode breaker has cleared the arc-back. The semihigh-speed cathode breaker is also useful for normal emergency trip of the entire cell line.

Station Control

The station operator's control devices for controlling a station similar to that shown in Figures 3 and 4 are concentrated on an operator's control board.

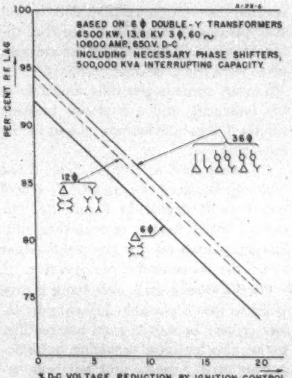

Figure 6. Power-factor characteristics for varying amount of grid control

The operator's functions in energizing such a cell line or taking it off the line are relatively simple. For energizing the cell line, the auxiliary circuits for water and vacuum pumps are energized, and then the a-c circuit breakers are closed. The anode and cathode breakers are next closed with the ignition circuit de-energized. The ignition circuit is then energized, permitting the rectifiers to take load. As previously mentioned, the d-c breakers cannot be closed with the ignition circuit energized, because the first breaker closed will trip again due to overload.

For some types of cell lines, and under some conditions, the operator may wish to start the cell line with the lowest possible d-c voltage permitted by ignition control, and energize the ignition circuit only after it has been retarded. All of these operations are performed at the operator's control board shown in Figure 3.

A cell line can be de-energized by simply tripping the cathode breakers. If one of the cathode breakers should lag materially behind the others, it will be forced to interrupt the entire cell-line current which represents an exceedingly heavy duty. If the operator desires and has the time, he may reduce the current interrupted by these breakers by first reducing the voltage and current on the entire cell line through the ignition control.

The power to cell lines should not be interrupted by de-energizing the ignition circuit. If this is attempted, the entire cell-line current somewhat attenuated will be finally transferred to a single anode. This is a serious overload for the particular anode and may cause serious damage to it. Even if all the cathode breakers are tripped simultaneously, they will open at slightly different moments. However, the magnetic energy stored in the cell-line circuit is dissipated quickly and without harm in the arc chutes of the cathode breaker.

Another method of de-energizing the cell line is to open the main a-c feeder breakers, a method which would correspond to the case of a complete power failure. Except for increased maintenance on the breaker, such interruption will not have any particularly bad effects, because the energy flow from the system is interrupted, and the current is transferred finally to the last conducting anode, only after it has died down to a relatively low and safe value.

Such stations as those illustrated by Figures 3 and 4 are continuously attended. The operations under normal circumstances are relatively simple and are usually confined to the observation of the instruments and the rectifiers. Where no automatic current nor voltage regulation is used, it is necessary to adjust the voltage from time to time by operating the tap changer or load-ratio control of the transformer, and perhaps occasionally to balance the load between the rectifiers by means of a slight amount of ignition control.

Temperature-Regulating Equipment

The losses in the rectifiers are usually removed by water cooling. There are a few installations of air-cooled rectifiers in Europe but no important installations in this country. In water-cooled rectifiers, the coolant is usually recirculated through some form of heat exchanger. Where the raw water supply is sufficiently cool,

clean, and abundant, these heat exchangers are generally water-to-water. Where the water supply is less favorable, these heat exchangers may be water-to-air.

The temperature-regulating heat exchangers as shown in the typical station layout of Figure 5 are usually located directly beneath the rectifier and the coolant continuously circulated between the rectifier and the heat exchanger. For most efficient rectifier operation, the temperature of this coolant is maintained at approximately 47 degrees centigrade. Thermostatically controlled valves on the heat exchanger maintain this temperature by automatically controlling the amount of raw cooling water flowing through the heat exchanger.

The recirculated liquid coolant is usually distilled water and may be treated with sodium dichromate to inhibit corrosion. These water-to-water heat exchangers can be manufactured for cooling water temperatures as high as 35 degrees centigrade (95 Fahrenheit). For a 36,000-kw rectifier installation considered in Figure 4, there would be required 420 gallons per minute of 85 degrees Fahrenheit raw cooling water.

In water-to-air heat exchangers, the coolant is also continuously circulated between the heat exchanger and the rectifier. A by-pass valve, thermostatically controlled, will pass more or less of the recirculated coolant through the heat exchanger while the fans run continuously.

Heat exchangers, when sodium-dichromate corrosion inhibitor is used, are at cathode potential and are therefore usually insulated from ground. Rubber hose is used to connect it to the rectifier and to the raw water supply.

The use of water-to-air heat exchangers, because of blower losses, may lower the station efficiency perhaps one tenth of one per cent, but since these blowers operate at full speed only a few months in the summer time, this is not an important consideration. The choice of water-to-water or water-to-air heat exchangers should only be considered from the standpoint of expense and quality of the raw water supply available. The installed cost of the water-to-water heat exchangers is considerably less than water-to-air, if the raw water is delivered to the building at no cost.

Station Arrangement

A typical station arrangement for a large electrochemical installation is shown in Figures 5A and 5B.

The transformers are installed outdoors and are usually of the oil-insulated self-cooled type.

The temperature-regulating heat exchangers are installed on the first floor of the main rectifier building directly below each of the rectifiers to which they are connected. For such large installations this arrangement gives the best economy of building space.

The rectifiers are mounted on the second floor at about the same elevation as the transformer secondary connections. Bus connections to the individual rectifier anodes are made preferably below the rectifier assembly. The cathode connections to the cathode breakers are also made from below. In this particular illustration, the neutral or negative connection from the interphase transformer is carried across the station directly below the roof.

The d-c breakers may be installed either on the ground floor or on the rectifier floor. An argument in favor of installing them on the rectifier floor is that the operator is then able to see that the breakers on a particular rectifier are open when work has to be done on this rectifier. However, space is generally available in the basement, and a narrower building results if these devices are placed in the basement.

On the second or rectifier floor of the building, is placed the operators' control board as illustrated in Figure 3. The control boards for two or even three potline equipments may be grouped together and under the control of one operator.

On the ground floor, aisle space is provided so that a portable degassing transformer may be moved from one rectifier to the other for initial degassing, or for degassing after a single unit has been returned to service after repairs.

The control cubicles containing the control devices for the pump and other auxiliaries for each rectifier are installed on the end of each rectifier.

The a-c switchgear in this particular illustration of Figure 5A is shown located in a separate building with the two autotransformers adjacent thereto.

It should be noted that this installation is typical of many electrochemical installations in that all of the 13.8-kv power cable enters the transformers and switchgear through pot heads, and there are no exposed 13.8-kv bushings in the system. This protection is a matter of some importance to those electrochemical installations where corrosive atmospheres or conducting dust is present.

A-C Power Supply

Reliability of power supply for electrochemical installations is considered essential, since loss of power even for a short time may be very costly, in addition to being naturally objectionable from the standpoint of the operator. In the case of chlorine cell lines, loss of power requires the immediate stoppage of auxiliary gas pumps and of the feed to the cells; otherwise chlorine gas may be liberated in the cell room with undesirable effects on the operators and the surrounding neighborhood. With aluminum and magnesium plants, the loss of power for an hour or more may cause the cells to freeze. In general, loss of power may mean an interruption of production for a much longer period than the duration of such power interruption and may require a costly and slow restarting of the process.

Therefore, the electric equipment and its power supply, which are the heart of this process, must be of the most reliable type and must include such spare capacity as may be indicated by experience. Even the best or most efficient or most reliable electric equipment will have an installed cost not usually exceeding 30 per cent of the total installed cost of the entire electrolytic plant which it supplies.

As shown in Figure 4, two autotransformers supply each pot line so that the reliability of power supply is insured, at least on a reduced basis if one autotransformer or its cable feed is lost. Each autotransformer has a continuous rating of two thirds of a pot line.

By proper separation of circuits, even these large electrochemical installations may be kept within a 500,000-kva short-circuit capacity breaker. Normal distribution voltage in well over 90 per cent of the electrochemical installations in the United States is 13.8 kv.

The double bus systems shown on the output side of the autotransformers permit any of the six main rectifier transformers to be connected to either of the autotransformers. While not indicated in Figure 4, the double bus system permits the autotransformers to be connected to different bus sections with no interconnections between feeders. This would be particularly important, if each autotransformer is fed from a different bus section in the powerhouse, and these powerhouse bus sections are tied together through a synchronizing or transfer bus. The fact that there is no interconnection on the output side of the autotransformers avoids any possibility of by-passing the synchronizing bus.

The outdoor substation supplying the three pot lines should logically have 45-degree transformers, to be consistent with the rectifier transformer practice. In the arrangement shown in Figure 4, the main stepdown transformers are provided with

fans, so that, in the event of the loss of one bank, the fans can be started on the remaining two banks, and power transferred to them through the transfer bus.

The transfer bus is normally disconnected and the bus sections *A*, *B*, and *C* are independent, thus localizing the effects of short circuits and other disturbances.

Because of the current-carrying capacity required on the main outdoor transformer bank, Figure 4 indicates that the delta for the secondary windings of these transformers is made on the metal-clad bus by using two 2,000-ampere, triple-pole breakers. This is a method frequently resorted to in order to obtain the necessary current-carrying capacity in metal-clad switchgear.

The system should, of course, be supplied with two-incoming high-voltage lines, in accordance with the standards of reliability required. Since interruptions on the incoming high-voltage lines are the most frequent, the cost of high-voltage circuit breakers and protective relaying is justified.

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Factors Affecting the Mechanical Deterioration of Cellulose Insulation

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Synopsis: The rate of mechanical deterioration of cellulose insulation is dependent on the conditions of its use. Those factors of major importance are the temperature applied and the presence of oxygen and moisture. Moisture even in small amounts greatly affects the mechanical stability of the cellulose insulation. In general, the mechanical life of the insulation is reduced by half for each doubling in water content. Deterioration promoted by oxidation is most effective at temperatures below 120 degrees centigrade and is accelerated by the presence of moisture.

The rate of deterioration for substantially dry insulation at temperatures above 120 degrees centigrade is dependent upon its previous history. Intermittent exposure to high temperature effects are additive. The "eight-degree-centigrade rule," indicative that the rate of mechanical deterioration is doubled for each eight-degree-centigrade increase from a base temperature of 120 degrees centigrade or higher, applies most closely for practical use when the insulation under study has lost more than 50 per cent of its tensile strength.

CELLULOSE insulation is widely used as the dielectric in high-voltage electric apparatus. Like mineral oil with which it is usually associated, cellulose in commercial practice is subject to chemical change to an extent which is dependent upon the conditions of its use. The deteriorating effects of temperature and oxygen are generally recognized and have been the subject of exhaustive research and discussion. The effect of moisture, as described in this paper, has not been carefully evaluated in previous studies of cellulose stability, despite the fact that it appears to play a dominant role in the chemical and mechanical changes exhibited by the cellulose when exposed to temperatures within the range encountered in the commercial use of transformers and other high-voltage electric apparatus.

As a material for insulating electric apparatus cellulose is used in a variety of forms. In its widest application cellulose is used in the form of paper sheets or tapes for the insulation of conductors which may vary greatly in size and shape. In some applications it is subjected to relatively low electric stresses and serves chiefly as a spacing material for the separation of adjacent conductors. In other applications it is subject to severe electric stress which in the case of capacitors and similar apparatus may be as high as 300 or 400 volts per mil. In most of its uses the cellulose is impregnated with mineral oil or varnish or both. It may, on the one hand, be found in apparatus operating under conditions allowing more or less free access of air or, on the other hand, in apparatus where contact with air or other source of oxygen is substantially eliminated by the use of hermetically sealed containers or by other means. In all of its applications, however, it is essential that chemical deterioration of the cellulose, resulting in the loss of dielectric efficiency and mechanical strength, shall be completely eliminated or carefully controlled in order that the insulation may be able to withstand the severe electric and mechanical stresses set up, not only in the normal use of the apparatus but also under short circuit or overload conditions.

One of the most difficult of all engineering problems is the translation of laboratory "life" data into terms of practical usage. The present paper concerns itself entirely with laboratory data correlating those factors of time, temperature, moisture, and oxidation which have been found to be important in affecting the mechanical stability of cellulose insulation. The results obtained are reported in order to assist the engineer in his efforts to use materials efficiently. The relative importance of the deteriorating factors investigated can only be finally determined from a study of the results obtained under the conditions of commercial use.

Objects of Investigation

In a previous paper[1] it has been related that the chemical and mechanical deterioration of cellulose is a complicated phenomenon greatly influenced by the decomposition products formed as a result of the chemical changes involved. Among those products are organic acids, water, hydrocarbons and their derivatives, and gases such as the oxides of carbon. It has been demonstrated that once initiated the chemical changes involved are accelerated to a degree dependent on the retention of the decomposition products. The present paper has as one of its objects the evaluation of the influence exerted by the presence of moisture on the mechanical stability of cellulose when aged under conditions which do not allow the escape of the deterioration products formed.

It has already been shown[2] that cellulose sheets or tapes will deteriorate mechanically when heated even in the absence of oxygen. The pyrochemical effect as contrasted to the effects of severe oxidation become pronounced as the temperature is raised above 120 degrees centigrade. Cellulose when heated passes through a "stable period" during which the mechanical properties are maintained. The presence of oxygen is chiefly effective in reducing the duration of this "stable period." It is a further object of this paper to demonstrate the effect of moisture on the duration of this "stable period."

Cellulose insulation as in transformers is subject to wide variations in temperature. Under overload conditions localized temperatures are obtained far in excess of those normally associated with the daily use of the apparatus. Engineering practice is to assume that the effects of such abnormal temperatures are additive. It is another object of this paper to examine the validity of such an assumption.

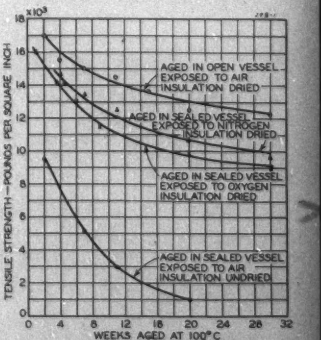

Figure 1. Showing the effect of testing conditions on the mechanical stability of 0.003-inch Manila insulating paper when aged under mineral transformer oil at 100 degrees centigrade

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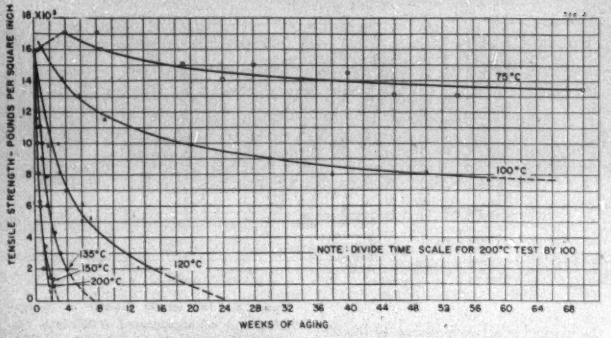


Figure 2. The tensile strength of vacuum-dried and oil-impregnated 0.003-inch Manila insulating paper as affected by aging in sealed containers under oil, the surface of which was in contact with oxygen gas

Chemical reactions involving organic materials are accelerated by heat. In a general sense, it is accepted that such chemical reactions are increased twofold for each ten-degree-centigrade increment in temperature. Montsinger in previous publications[3,4] has called attention to the importance of properly evaluating the influences of temperature as a criterion of the ability of transformer insulation to withstand the effects of temporary overloads encountered in the use of transformers. He has suggested the "eight-degree rule," indicative that the rate of the mechanical deterioration of cellulose doubles for each eight-degree-centigrade rise in temperature. It is a final object of this paper to demonstrate the rate of cellulose deterioration as affected by temperature increase under widely different conditions of possible use.

Testing Technique

Experience in the study of cellulose deterioration at elevated temperature demonstrates the necessity of closely controlling all those factors which have long been recognized as of fundamental importance in the study of sludge formation in mineral transformer oil.[5,6] The temperature must be carefully controlled. In order to obtain duplicate test results, the temperature should be controlled to ±0.5 degree centigrade.

The testing receptacle in which the cellulose is aged must be carefully selected if reproducible results are to be obtained. Access of air or other gases must be controlled. The ease of escape of products formed as a result of the deterioration must be clearly described and evaluated in terms of practical usage. The widely different results (Figure 1) accompanying a change in the conditioning treatment of the insulation or in the design of the vessel used for the aging only serve to emphasize the confusion which may arise when details of this type are ignored.

In the "sealed-tube" tests hereinafter described, the tube is of Pyrex glass and measures 200 millimeters in length and 25 millimeters in diameter. When sealed it has a volume of 59 milliliters. The conditioned oil and the oil-immersed paper insulation fill the tube to the 50-milliliter mark, the remaining 9 milliliters being filled with the stated gas conditioned as described. The paper used is cut before conditioning in strips, each one-half inch wide and ten inches long. The paper used throughout this study is 0.003-inch Manila cable paper. Ten strips of such paper, conditioned as described, are used in each test. This gives a ratio of approximately one-quarter pound of paper per gallon of oil. The tensile strength of the paper is determined in a room maintained at 65 per cent relative humidity, 70 degrees Fahrenheit. The oil-impregnated papers are tested immediately after having been taken from immersion in the oil. The tensile strength is determined in a Schopper testing apparatus. The results reported are the average of ten individual tensile strength tests.

The mineral oil used throughout this paper is a typical American transformer oil (58 seconds Saybolt Universal viscosity at 37.8 degrees centigrade) and is manufactured from Gulf Coast crude. Before use it is completely degassed and dried. During test it is saturated with the gas with which it is in contact, as is described in each particular instance.

Moisture Determination

The problem of determining the moisture content of cellulose sheets has been recognized as difficult and subject to variation because of the instability of the cellulose itself. Urquhart and Williams[7] have determined that oven drying at 110 degrees centigrade are as satisfactory as vacuum drying over phosphorous pentoxide at 15 degrees centigrade. Such methods may be well suited for roughly determining the water content of cellulose containing large amounts of moisture, such as is present in ordinary paper exposed to atmospheric conditions, but they fail to give accurate test values when the water content of the paper is materially reduced.

A satisfactory method of test for determining the water content of insulating papers has been established as follows:

Approximately 50 grams of paper, preferably cut into pieces about three by three-fourths inches in size (less weight of paper if suspected to be high in water content, more weight if suspected to be of low water content) is immersed quickly in 500 milliliters of dry liquid such as mineral transformer oil contained in a thoroughly dry 1,000-milliliter round bottom flask. Dry nitrogen gas is passed through the liquid at the rate of 100 milliliters per minute with a fritted gas washing tube to obtain the best dispersion. The temperature of the liquid is raised to 110 degrees centigrade plus or minus two degrees. The gas after passing from the liquid-paper suspension is passed through two liquid air-cooled traps connected in series where the moisture and other volatile materials are condensed. The outlet for the nitrogen gas is protected by a conventional drying tube to prevent suck back of atmospheric moisture. The nitrogen gas is passed through the test flask for three hours after which the water collected in the liquid air traps is quantitatively determined. The nitrogen gas treatment is repeated in three-hour steps at 110 degrees centigrade until all water has been driven from the paper under test. The quantitative test for the water collected is carried out as follows:

Ten milliliters of an acetyl chloride solution in dry benzene (118 grams per liter of solution) are added to a dry 250-milliliter glass stoppered flask and cooled in an ice bath. Two milliliters of dry pyridene are added dropwise to the acetyl chloride solution with continual shaking. A white precipitate of acetyl chloride-pyridene complex is formed.

The frozen condensate in the traps is dissolved in 25 cubic centimeters of dry acetone and added to the cold acetyl chloride-pyridene complex. The acetone is added in 5-5-2.5-2.5 milliliter portions to the first trap and in 5-2.5-2.5 milliliter

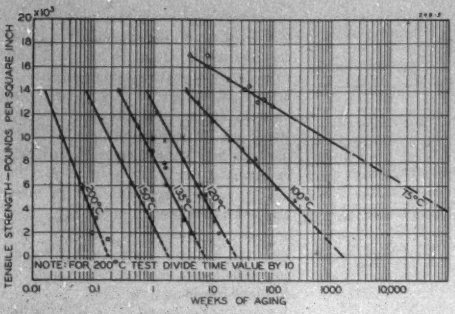


Figure 3. The tensile strength of vacuum-dried and oil-impregnated 0.003-inch Manila insulating paper as affected by aging in sealed glass containers under oil, the surface of which was in contact with oxygen gas

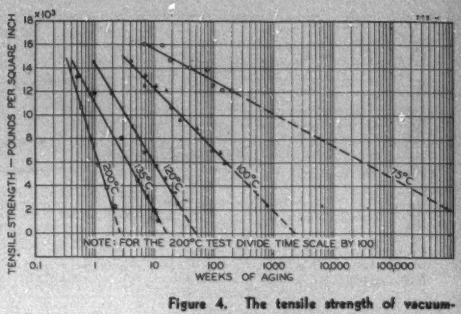


Figure 4. The tensile strength of vacuum-dried and oil-impregnated 0.003-inch Manila insulating paper as affected by aging in sealed glass containers under oil, the surface of which was in contact with nitrogen gas

portions to the second trap. The stoppered flask is then removed from the ice bath and allowed to stand at least 15 and not more than 30 minutes with occasional shaking out of contact with direct sunlight. Four milliliters of dry ethyl alcohol are added and the mixture is well shaken. Sixteen milliliters more of dry ethyl alcohol are then added and after being shaken and allowed to stand for five minutes, the mixture is titrated with 0.5 normal sodium hydroxide to a phenol phthalein end point. A blank test is run with all conditions identical in order to correct for residual moisture in the reagents and apparatus. The amount of moisture in the paper, expressed in terms of its dry weight is then calculated.

Using this procedure definite and reproducible test results have been obtained. Care must be taken, however, to avoid decomposition and subsequent removal of the "water of constitution" from the cellulose sheet. If the analysis be carried beyond the point at which the water evolution from the paper drops to zero, subsequent heating will result eventually in some decomposition of the cellulose.[1] The formation of water as a result of this decomposition will obscure the real moisture content determination.

The determination of the moisture content of a cellulose sheet is difficult and fraught with many technical pitfalls. The method described gives results which appear lower than those heretofore reported for mineral oil-treated cellulose insulation.[11] Pending further experimental data, the moisture contents described in subsequent paragraphs might well be considered as "relative" rather than as fixed and absolute values. Such a precaution in no wise diminishes the importance of the studies demonstrating the marked effect of moisture on the mechanical life of the cellulose insulation.

Expression of Test Results

Because of its greater degree of reproducibility, the tensile test has been adopted as the gauge of mechanical strength of the cellulose sheet and its rate of deterioration. Typical time relationships are illustrated in Figure 2. Because of the difficulty in clear presentation, however, such relations are not generally used in this paper. The semilogarithmic relationship between the tensile strength and the duration of aging have been found to be better suited for clear presentation (Figure 3).

The Effect of Temperature

There are many technical processes which employ cellulose products at high temperature. This has led to the initiation of many researches concerned with the stability of cellulose products over short periods of heating. The general conclusion reached has been that cellulose suffers some decomposition at temperatures above 150 degrees centigrade. The problem of the insulation engineer however is the problem of time and temperature. The stability of cellulose during short periods of heating[1,2] are frequently misleading. Knecht[8] has shown that, when cotton is heated for 336 hours at 80 degrees centigrade, chemical changes occur which endow the cellulose with reducing powers. It is the effect of these often overlooked chemical changes, culminating in mechanical deterioration, with which this paper is concerned. The time of heating is obviously of importance.

The effect of time and temperature over the range from 75 to 200 degrees centigrade on the tensile strength of vacuum-dried and oil-impregnated 0.003-inch Manila paper is illustrated in Figure 2.

During the aging runs the insulation was immersed in dry oil in sealed Pyrex glass tubes, the surface of the oil being in contact with oxygen as already described. The semilogarithmic relation of tensile strength and time of heating is illustrated in Figure 3. Figure 4 illustrates similar data for vacuum-dried, oil-impregnated 0.003-inch Manila paper, the surface of the oil in which the paper is immersed being in contact with dry nitrogen gas. The marked effect of temperature on the mechanical stability of Manila paper is illustrated in Figure 5 which shows the "50 per cent life" in tensile strength over

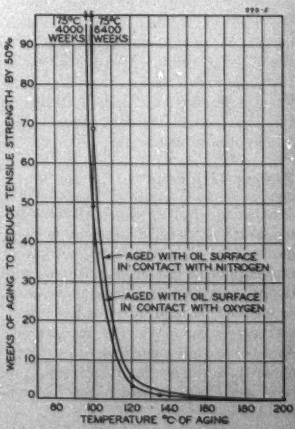

175°C 4000 WEEKS
75°C 6400 WEEKS
WEEKS OF AGING TO REDUCE TENSILE STRENGTH BY 50%
AGED WITH OIL SURFACE IN CONTACT WITH NITROGEN
AGED WITH OIL SURFACE IN CONTACT WITH OXYGEN
TEMPERATURE °C OF AGING

Figure 5. Showing the marked effect of temperature increase above 75 degrees centigrade in the mechanical life of vacuum-dried and oil-impregnated 0.003-inch Manila insulation paper when aged in sealed glass containers under oil, the surface of which was in contact with oxygen or nitrogen gas as indicated

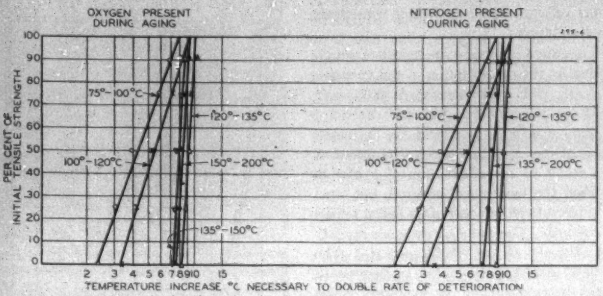


Figure 6. The rate of mechanical deterioration of vacuum-dried and oil-impregnated 0.003-inch Manila paper becomes more sensitive to temperature increase as the deterioration progresses

The effect is most pronounced when the temperature of test is below 120 degrees centigrade

the temperature range from 75 to 200 degrees centigrade. It is clearly evident that as the temperature rises above 75 degrees centigrade the deterioration proceeds at a rapidly increasing rate. It is the proper evaluation of this rapidly increasing rate of deterioration which is of fundamental importance in the application of cellulose insulation in high-voltage electric apparatus.

Inspection of the data presented in Figures, 2, 3, 4, and 5 at once leads to the conclusion that the rate of mechanical deterioration of Manila insulating paper cannot be expressed in terms of any single temperature expression. Figure 6 plots as a semilogarithmic expression the relation between the deteriorating mechanical strength and that temperature rise which is necessary in order to produce a twofold increase in the mechanical deterioration over the temperature range shown. For temperatures in the range from 75 to 100 degrees centigrade the effect of temperature change is extremely marked, whether the deterioration be produced in the presence or absence of oxygen. In this range, an increase in temperature of but 2.4 degrees centigrade will reduce the total life of the insulation by half. With temperatures of 120 degrees centigrade and higher, however, the deterioration is less sensitive to temperature increase. To double the rate of deterioration for these higher temperatures (reduce the total life by half), an increase ranging between approximately seven and ten degrees centigrade is necessary. The relation of the temperature of the aging to that temperature increase necessary to produce a twofold rate of deterioration when the tensile strength has been reduced to 50 per cent and zero per cent of its initial value is illustrated in Figure 7. The so-called "eight-degree rule" suggested by Montsinger is a good practical compromise for the higher temperatures of use (120 degrees centigrade and higher) when the tensile strength has been reduced to less than about 50 per cent of the initial value.

The Effect of Oxygen

The problem of evaluating the practical effect of oxygen on the mechanical strength of cellulose insulation during the normal use of a transformer or similar apparatus is difficult, because of the wide differences in transformer designs. The transformer designs of greatest importance for consideration, however, are the hermetically sealed type containing a gas cushion and the conservator type. Each of these has a limited supply of available oxygen. In the conservator transformer the amount of oxygen is limited to that carried into the transformer as an air solution in the mineral oil. In the hermetically sealed transformer the amount of oxygen is limited to that present in oil solution and in the gas cushion when the transformer is sealed. When this gas cushion consists of nitrogen gas, the amount of oxygen available within the transformer is negligible if the mineral oil is properly deaerated before the transformer is sealed.

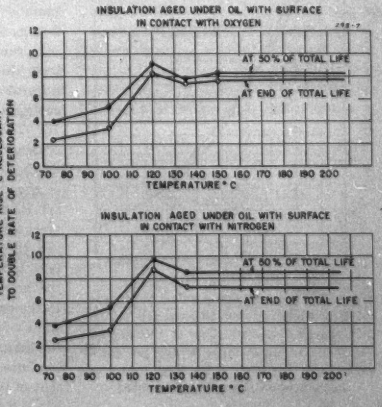

INSULATION AGED UNDER OIL WITH SURFACE IN CONTACT WITH OXYGEN
AT 50% OF TOTAL LIFE
AT END OF TOTAL LIFE
TEMPERATURE RISE °C NECESSARY TO DOUBLE RATE OF DETERIORATION
TEMPERATURE ° C
INSULATION AGED UNDER OIL WITH SURFACE IN CONTACT WITH NITROGEN
AT 50% OF TOTAL LIFE
AT END OF TOTAL LIFE
TEMPERATURE ° C

Figure 7. The "eight-degree rule" correlating temperature increase and mechanical deterioration of vacuum-dried and oil-impregnated 0.003-inch Manila paper applies with practical accuracy when the paper has deteriorated to at least 50 per cent of its initial value at temperatures of 120 degrees centigrade and higher

In the laboratory study of the effects of oxidation on the mechanical strength of the cellulose insulation, an attempt has been made to exaggerate the hermetically sealed transformer design. The sealed tubes have been filled with oil and the oil-immersed insulation to 85 per cent of the volume. The gas cushion occupies the remaining 15 per cent of the volume. These are the approximate relationships of oil to gas volumes in the average hermetically sealed transformer. The effect of oxidation has been exaggerated by the use of pure oxygen in the gas space. Pure oxygen has been used to exaggerate the oxidation possibilities, since in a previous publication[3] the presence of air has been demonstrated to be of negligible oxidation effect within the duration of the laboratory tests made. The use of this type of test arrangement is considered to be more severe than the conditions which are met in either the conservator or the hermetically sealed type of oil-filled transformer.

It has been suggested[10,12] that the effect of oxygen on the mechanical deterioration of oil-treated cellulose insulation involves consideration of the acids formed as a result of the oxidation of the oil itself. In a general sense this is true. Therefore, since the most corrosive acids formed both from the oil oxidation and from the oxidation of the cellulose are volatile at the temperature of the tests described, sealed containers have been used for the aging study. This insures that all products of decomposition and oxidation, whether from the oil or from the cellulose, are retained within the test receptacle. From the practical standpoint this procedure is justified, since the mechanical deteriora-

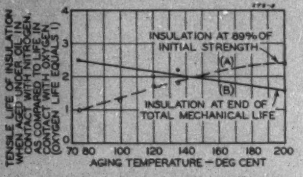

TENSILE LIFE OF INSULATION WITH OXYGEN PRESENT IN CONTACT WITH NITROGEN, AS COMPARED TO LIFE IN NITROGEN ALONE (OXYGEN LIFE EQUALS 1)
INSULATION AT 89% OF INITIAL STRENGTH
(A)
(B)
INSULATION AT END OF TOTAL MECHANICAL LIFE
70 80 100 120 140 160 180 200
AGING TEMPERATURE — DEG CENT

Figure 8. The elimination of oxygen increases the initial stability of vacuum-dried and oil-impregnated 0.003-inch Manila paper over the temperature range 75–100 degrees centigrade

The total life of the insulation, however is progressively less affected by the elimination of oxidation as the temperature of the aging is increased

tion reported therefore includes consideration of the accumulated effects of all the oxidation and decomposition that occurs.

In a previous publication[2] it was concluded that the "single effect of oxidation was restricted to the initial periods of treatment at temperatures lower than 120 degrees centigrade. At higher temperatures pyrochemical decomposition occurs . . ." The data presented extend and support this conclusion and indicate that the major effect of oxidation is produced when the insulation is exposed to the lower testing temperatures. At 75 degrees centigrade the deterioration due to oxidation becomes more pronounced as the mechanical aging progresses. At higher temperatures the pyrochemical decomposition of the cellulose tends to reduce the effects of oxidation.

Figure 8 illustrates the effect of oxidation on the deterioration of the vacuum-dried and oil-impregnated 0.003-inch Manila paper for two degrees of deterioration. Curve *A* illustrates the increased life of the insulation which is obtained as a result of the elimination of oxidation when the mechanical strength has been reduced to 89 per cent of its initial tensile strength. This value corresponds roughly to the end of the "stable period." The effect of oxygen elimination increases with the temperature of the exposure. This supports the conclusion that the duration of the "stable period" is reduced by oxidation processes. When, however, the total life of the insulation is considered (tensile strength zero), curve *B* supports the conclusion that the occurrence of pyrochemical decomposition during the later stages of the cellulose aging becomes more pronounced with the higher testing temperatures and reduces the beneficial effects normally associated with the elimination of oxygen.

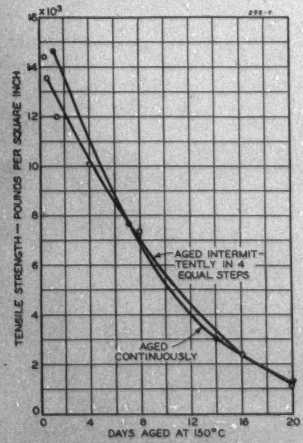


Figure 9. The mechanical aging of vacuum-dried, oil-treated, and oil-immersed 0.003-inch Manila insulating paper at 150 degrees centigrade in the presence of nitrogen gas is an additive function of the total period of heating when intermittently applied

Intermittent Aging

The total aging of cellulose insulation when exposed intermittently to high temperatures necessarily includes the deterioration which occurs during the heating and cooling periods. To determine whether the intermittent application of high temperature is strictly additive, the insulation contained in the sealed glass tubes was heated as rapidly as possible by immersion in an oil bath maintained continuously at 150 degrees centigrade, and cooled rapidly by transfer to an oil bath maintained continuously at 25 degrees centigrade. This reduced the effect of the heating and cooling periods to a minimum. The effect of such intermittent heating and cooling on the tensile strength of vacuum-dried, oil-impregnated, 0.003-inch Manila insulating paper aged under mineral transformer oil at 150 degrees centigrade is illustrated in Figures 9 and 10. The intermittent aging relation was obtained by heating the insulation at 150 degrees centigrade for four equal periods of time. Between these heating periods the insulation was maintained at 25 degrees for 24 hours. In the absence of oxygen, the effect of intermittent heating has been found to be strictly additive within the limits of experimental error (Figure 9). In the presence of oxygen (Figure 10) the additive effect again appears to be within the limits of experimental error until the insulation has lost approximately 50 per cent of its initial tensile strength. For a greater degree of deterioration the effect of intermittent aging appears less than additive, although the differences observed do not appear of major significance. Pending further investigation, it is concluded that the results obtained justify the engineering practice which considers the effects of intermittent heating at high temperature to be additive.

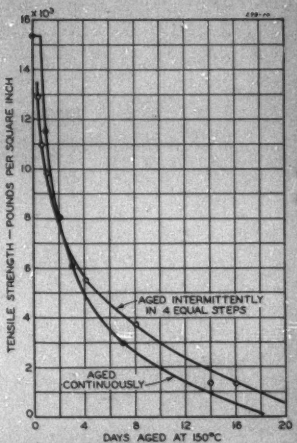


Figure 10. The effect of intermittent heating at 150 degrees centigrade on the mechanical strength of vacuum-dried, oil-treated, and oil-immersed 0.003-inch Manila insulating paper in the presence of oxygen

The Effect of Moisture on the Tensile Strength

Inspection of the data presented (Figure 6) correlating the effect of temperature on the rate of mechanical deteriora-

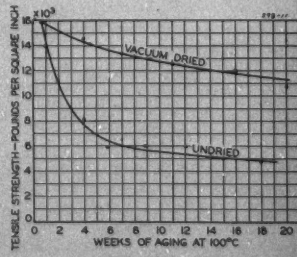


Figure 11. Showing the effect of moisture retained by cellulose in its normal condition on the mechanical stability of 0.003-inch Manila insulating paper during an aging run at 100 degrees centigrade in sealed glass tubes

During the aging the insulation is held under mineral transformer oil, the surface of which is in contact with nitrogen gas

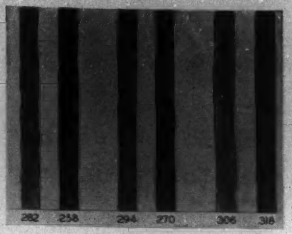


Figure 12. Illustrating the color darkening which accompanies the mechanical deterioration obtained when 0.003-inch Manila paper is aged in sealed tubes for two weeks at 120 degrees centigrade in the presence of moisture

Samples 282, 294, and 306—paper aged after having been vacuum dried and impregnated with mineral transformer oil, the surface of which is in contact with oxygen, nitrogen, and air respectively

Samples 258, 270, and 318—paper aged immersed in mineral transformer oil without previous drying, the oil being in contact with oxygen, nitrogen, and air respectively

tion leads to the observation that as the deterioration progresses it becomes more sensitive to temperature change. Thus, although in the early stages of heating, the paper deterioration increases approximately twofold for each seven to ten degrees centigrade rise in temperature, when the tensile strength has been reduced to as low as 25 per cent of its initial value, the rate of deterioration doubles for an increase of only about 2.4 to 9 degrees centigrade, depending on the testing temperature. This acceleration of the deterioration has been traced[1] to the effect of decomposition products retained in the body of the cellulose. Among such decomposition products is water. Because of the ability of water through ionization and otherwise to activate many of the products (acids and acidic materials) formed when cellulose undergoes deterioration, it is not unexpected to find that the mechanical strength of cellulose insulation is affected by the presence of moisture in even small amounts. Figure 11 illustrates the greater stability in the tensile strength of 0.003-inch Manila insulating paper which is obtained when the insulation is freed of its moisture before exposure to high temperature. In one instance the paper is heated under oil at 100 degrees centigrade without vacuum drying. In the other instance the paper is first vacuum dried to a low moisture content. The greater mechanical instability of the undried paper is accompanied by other visual evidence of greater chemical change. In contrast to the dried paper, the undried insulation after aging is darkened, reacts acidic, and smells strongly of a caramel odor, characteristic of overheated cellulose. Figure 12 illustrates the marked darkening in color which accompanies the greatly accelerated mechanical deterioration in the cellulose sheet when aged in the presence of moisture, even though the possibility of oxidation be eliminated by the use of nitrogen gas.

The data of Figure 11 are obtained as a result of an aging run in sealed glass vessels. It is suggested that the extreme variations reported in Figure 1 are due to the difference in the design of the aging vessel. On the one hand, the moisture and other volatile products originally present or formed during the test were allowed easy escape since the vessel was open to the air. On the other hand, the moisture and volatile products were completely retained in the sealed tube during the aging run. The wide difference in the test results reported in Figure 1 and in Figure 11 illustrates the wide variation which can be expected when the insulation is aged without careful attention to all of the conditions affecting the chemical stability of the cellulose. Not the least of these conditions is its moisture content.

The Effect of Moisture on the Rate of Deterioration as Affected by Temperature and Oxidation

The presence of moisture in cellulose insulation is of such importance in its effect on the mechanical stability at high temperature that it tends to modify the relationships set up for the dried insulation. To illustrate this, 0.003-inch Manila insulating paper containing 1.5 per cent moisture has been immersed in oil and aged at 100 and 120 degrees centigrade in sealed glass tubes of the type already described, the surface of the oil being in contact with oxygen or nitrogen gas. The results obtained are illustrated in Figure 13.

It has already been shown in Figure 8 that with dry insulation the presence of oxygen produces its maximum effect on the total life of the insulation when the aging is carried out at the lower testing temperatures. At 75 degrees centigrade the total life is increased about 2.5 times when an inert gas such as nitrogen is substituted for oxygen, thereby eliminating substantially all of the deterioration attributed to oxidation. When, however, there is a substantial amount of moisture present, its deteriorating influence accentuates the effect of oxidation. Figure 14 based on the data of Figure 13 demonstrates that in the presence of moisture the elimination of the oxidation reaction at 100 degrees centigrade has a more pronounced effect than is associated with elimination of oxygen on the life of the dried paper insulation.

In like manner, the effect of temperature increase on the aging of Manila insulating paper is materially modified by the presence of moisture. The deterioration becomes less sensitive to temperature change. This is illustrated in Figure 15.

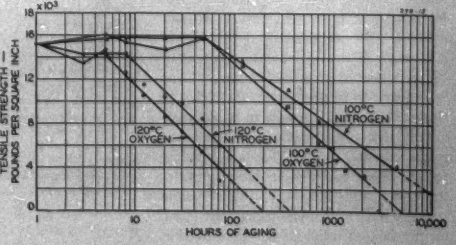


Figure 13. The aging of 0.003-inch Manila insulating paper containing 1.5 per cent moisture

Quantitative Effects of Moisture

The quantitative study of the effects of moisture on the mechanical aging of cellulose is made difficult by the fact that the equilibrium which exists between the amount of water retained by the cellulose and that present in the mineral transformer oil in which it is immersed shifts with changes in temperature.[9] The higher the temperature, the less water is retained by the cellulose. In the data relating to the water content of the cellulose in this and subsequent sections, the value given is the total water content of the oil and cellulose insulation within the sealed container at 25 degrees centigrade. At this temperature under the experimental conditions existing, substantially all of the water present is held by the cellulose and is so reported.

In order to eliminate the effects of oxidation which vary with the temperature of aging and the moisture content of the cellulose insulation, a typical set of test results, describing the deterioration of oil-impregnated and oil-immersed 0.003-inch Manila paper aged at 120 degrees centigrade in the presence of nitrogen, is selected to demonstrate the influence of

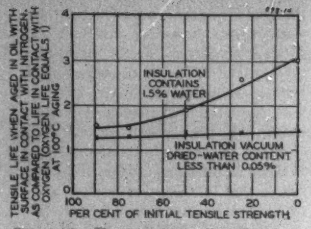

TENSILE LIFE WHEN AGED IN OIL WITH SURFACE IN CONTACT WITH NITROGEN, AS COMPARED TO LIFE IN CONTACT WITH OXYGEN (TENSILE LIFE EQUALS 1) AT 100°C AGING
INSULATION CONTAINS 1.5% WATER
INSULATION VACUUM DRIED-WATER CONTENT LESS THAN 0.05%
PER CENT OF INITIAL TENSILE STRENGTH

Figure 14. The importance of oxidation in promoting the mechanical deterioration of 0.003-inch Manila insulating paper is materially increased when the aging of the oil-treated and oil-immersed insulation is carried out in sealed tubes in the presence of moisture

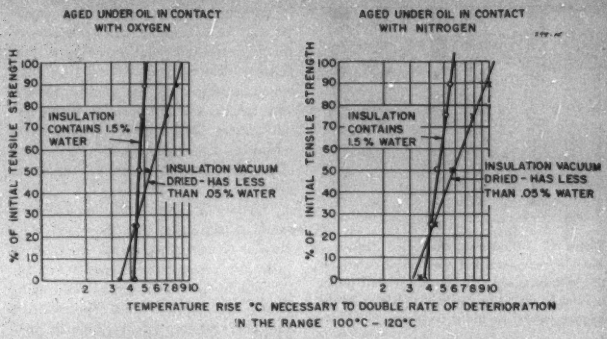

AGED UNDER OIL IN CONTACT WITH OXYGEN
AGED UNDER OIL IN CONTACT WITH NITROGEN
% OF INITIAL TENSILE STRENGTH
INSULATION CONTAINS 1.5% WATER
INSULATION VACUUM DRIED - HAS LESS THAN .05% WATER
TEMPERATURE RISE °C NECESSARY TO DOUBLE RATE OF DETERIORATION IN THE RANGE 100°C - 120°C

Figure 15. The presence of moisture in incompletely dried, oil-treated and oil-immersed 0.003-inch Manila insulating paper exaggerates the effect of temperature increase from 100 to 120 degrees centigrade during the major part of the mechanical life

The greater initial resistance to temperature increase characteristic of the well-dried insulation, however, is reduced as the result of water formation as the deterioration progresses

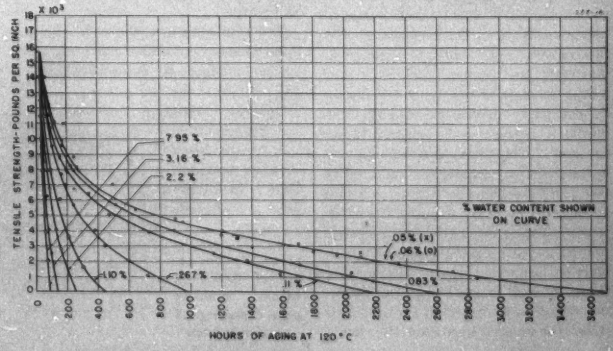
moisture. The insulation was first vacuum dried at 100 degrees centigrade for a period of time ranging from less than one hour to more than 100 hours, after which it was impregnated with gas-free, dry mineral transformer oil and sealed at once in glass vessels partially filled with the oil and oil-immersed insulation as already described. The gas with which the oil was saturated and with which the oil surface was in contact was dry nitrogen. The water content of the assembly was determined at the start of each aging run. The effect of moisture was marked. The total life of the insulation was reduced from a total of 3,700 hours (22 weeks), characteristic of the well-dried insulation, to a life of less than 100 hours (0.6 week), when the paper was substantially undried and contained about eight per cent moisture. Figure 16 represents the relationship found to prevail in a typical series of test results obtained simultaneously. As illustrated in Figure 17, there exists a logarithmic relation between the water content of the cellulose insulation and that period of time necessary to produce a given amount of mechanical deterioration in the cellulose sheet when aged at 120 degrees centigrade under the conditions applied.

In a previous paragraph it has been demonstrated that the effect of oxidation during the mechanical aging of cellulose insulation materially shortens the "stable period" during which the insulation can be heated at high temperature without evidence of mechanical deterioration. The effect of the initial water content of the cellulose of this "stable period" has been found to be negligible. In Figure 16 the stable period is shown to be approximately 40 hours, irrespective of the initial water content of the Manila insulating paper. Since oxidation is effective in determining the length of this "stable period" it is at once obvious that other testing factors which affect the oxidation reaction are of importance in determining its duration.

Because of the importance of mechanical stability in many of the dielectric applications of cellulose in electrical apparatus, the marked influence of moisture on the mechanical life of the insulation assumes practical value. Cellulose is a hygroscopic material and rapidly absorbs moisture from the surrounding medium.[9] The absorption of this moisture is effective in determining the subsequent rapidity in mechanical deterioration. From the data of Figure 16 it is obvious that, when oxidation is eliminated, the absorption of even small amounts of moisture by the dry insulation will materially reduce its mechanical life. Conversely, it is obvious that the absorption of relatively large amounts of moisture will have less effect on the aging of the improperly dried insulation. The relationship is illustrated in Figure 18.

To double the rate of mechanical deterioration in oil-treated and oil-immersed Manila paper in the absence of oxidation, the amount of moisture addition necessary is dependent upon the degree of deterioration which is selected for study. The total life of the insulation is halved (the deterioration rate doubled) by the addition of water equal to approximately 100 per cent of that originally present in the insulation. Thus, with a water content of 0.05 per cent, the life of oil-treated and oil-immersed Manila paper in the absence of oxygen is approximately 4,000 hours. With the absorption of an equal amount of moisture to give a total water content of 0.10 per cent, the total life of the insulation at 120 degrees centigrade is reduced to about 2,000 hours. On the other hand, to reduce by half the total

Figure 16. The effect of moisture content on the mechanical life of oil-impregnated and oil-immersed 0.003-inch Manila insulating paper when aged at 120 degrees centigrade in sealed glass containers, the oil surface being in contact with nitrogen gas



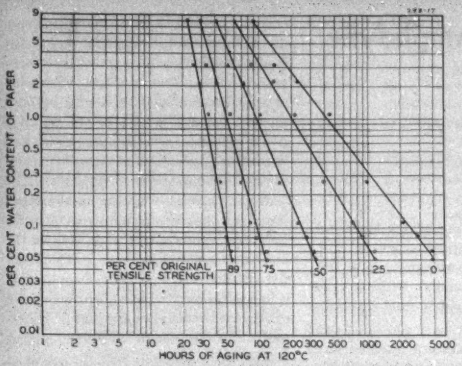


Figure 17. Under the conditions of test applying for the data of Figure 13, the water content of the cellulose insulation bears a logarithmic relation to the period of heating necessary to produce a given amount of mechanical deterioration

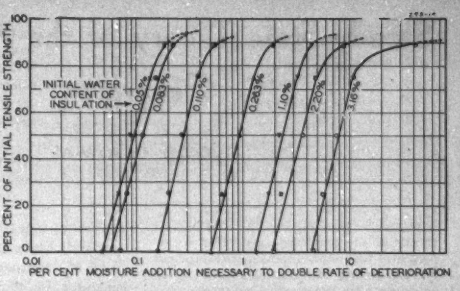


Figure 19. Illustrating the semilogarithmic relation which exists between the degree of mechanical deterioration of oil-treated and oil-immersed 0.003-inch Manila insulating paper and the amount of moisture addition necessary to double the rate of deterioration (halve the life) when heated in sealed glass vessels, the surface of the oil being in contact with nitrogen gas

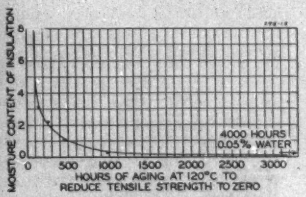


Figure 18. The elimination of moisture from cellulose insulation before being subjected to high temperature produces a rapidly increasing life as the moisture content is reduced below three per cent

Data based on the ultimate life values illustrated in Figure 16

life of the same insulation containing 3.16 per cent water from its value of 140 hours aged at 120 degrees centigrade, the addition of approximately 4.4 per cent more water is necessary. The relationship between the degree of mechanical deterioration of the oil-treated and oil-immersed 0.003-inch Manila insulating paper and the amount of moisture necessary to double the rate of deterioration (halve the life) in the absence of oxidation is shown in Figure 19.

Figure 19 is of importance. It demonstrates that as the point of mechanical strength selected for comparison approaches the original tensile strength of the insulation, the effect of water additions is reduced in the absence of oxygen, that is, greater water additions are necessary to reduce the life by half. This supports the observation that the "stable period," the length of time that the material can be heated without apparent mechanical change, is not greatly affected by changes in the water content of the insulation. Figure 19 also indicates that the effect of water additions becomes more pronounced as the degree of deterioration of the insulation progresses. This supports the observation that those reagents active in promoting mechanical deterioration include acidic products formed as a result of the initial chemical changes, the action of which is made more severe because of the presence of moisture.

Summary Conclusions

The general conclusions which are drawn from this investigation are:

1. The rate of mechanical deterioration in cellulose insulation depends on the conditions of its use. Among those factors of major importance are the temperature applied and the presence of oxygen and moisture.

2. As the temperature is raised above 75 degrees centigrade, the mechanical deterioration of cellulose insulation proceeds at a rapidly increasing rate.

3. Oxidation is most effective on the total mechanical life of the cellulose when the insulation is aged at temperatures below 120 degrees centigrade.

4. The effect of intermittent heating at 150 degrees centigrade on the mechanical deterioration of cellulose insulation is additive.

5. The mechanical life of a cellulose sheet is radically reduced when the water content of the dry insulation is increased in amount up to approximately 0.5 per cent of its dry weight. In general terms, the mechanical life of cellulose insulation is reduced by half for each 100 per cent increase in water content.

6. The effect of oxidation on the mechanical life of cellulose insulation becomes more pronounced in the presence of moisture.

7. The rate of deterioration for the substantially dry insulation as affected by temperature increase above 120 degrees centigrade is dependent upon its previous history. The "eight-degree rule," indicative that the rate of mechanical deterioration is doubled for each eight-degree-centigrade increase from a base temperature of 120 degrees centigrade or higher, applies most closely for practical use when the insulation under study has lost more than 50 per cent of its initial tensile strength.

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Steady-State Theory of the Amplidyne Generator

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Synopsis: The fundamental steady-state theory of the amplidyne generator is presented in this paper together with methods for calculating the characteristics of the generator from the machine constants. Experimental data obtained on a test machine are compared with calculated results to show the accuracy of the methods and to substantiate the theory. The effects of such factors as brush losses, commutation, and overcompensation and undercompensation on the operation of the generator are explained. Overcompensated and undercompensated machines are treated from the standpoint of both steady-state operation and electrical stability. Methods are given for the determination of the machine constants from open-circuit and short-circuit tests performed on the machine. This method offers the advantage that the machine constants so determined apply for actual conditions of operation and need not be modified to include the effects of such factors as brush and commutation losses, eddy currents, and hysteresis.

THE amplidyne generator which has found wide industrial application in various types of control apparatus is closely related from the standpoint of operating principle to the Rosenberg generator and the metadyne, differing principally in the manner in which it is used. The Rosenberg generator is a constant current source of d-c electrical energy; the metadyne in its usual form is a machine for converting constant potential d-c energy into constant current d-c energy, while the amplidyne generator is a dynamoelectric power amplifier.

One of the outstanding features of the Rosenberg generator is that the open-circuit output voltage varies with the square of the speed for constant field excitation.[2] Therefore, the polarity of the machine is independent of the direction of rotation. When the terminal voltage is maintained constant, by a storage battery, for instance, the output current is essentially independent of the speed for very wide limits of speed variation. Because of these particular properties, this generator in conjunction with storage batteries has been widely used for train lighting service.[1,3,4]

Although the Rosenberg machine was first described in 1905,[1] apparently little was known as to the variety of characteristics this type of machine would assume if other coils in addition to the primary field were used in providing excitation. An investigation of this nature, conducted by J. M. Pestarini in France and published in 1930,[5–7] led to the conception of the metadyne. As defined by Mr. Pestarini, the metadyne is a generalized d-c machine consisting of a d-c armature and commutator, any number of field poles each of which may be excited in any manner, and any number of brushes arranged to bear on the commutator in positions for which satisfactory commutation can be obtained. In accordance with this definition, all rotating d-c machines including the ordinary d-c generator are metadynes. In common usage, however, the term "metadyne" refers only to those several forms of d-c machine which convert constant potential energy into constant current energy. The "figure-eight-connected" metadyne was found suitable for electric locomotive control and was successfully applied to many of the electric railways in France[8] and later to electric traffic systems in England.[8,9] Modifications of this general scheme have been used in this country for control of the locomotives of modern streamlined trains.

Investigation by the General Electric Company of possible applications of different forms of the metadyne to the control of industrial apparatus led to the development of the amplidyne generator.[10–14] This machine, which falls into the general class of metadynes designated as "cross-connected," represents a generalization of the Rosenberg generator in which the field poles are excited by several coils supplied from different sources either internal or external to the machine.

The amplidyne generator is used principally as an element of control mechanisms and plays a part similar to that of the ordinary vacuum tube. It absorbs weak current or voltage signals, amplifies them, and delivers them to the next unit of the control mechanism at a greatly increased power level. This machine offers the principal advantage that it may be built at very reasonable cost to deliver large power outputs. On the other hand, it is limited in application because of its comparatively slow speed of response. The time lag between a change in the input signal and the corresponding change in the output is comparatively large, because the machine consists entirely of highly inductive circuits. Its chief field of application is in control mechanisms operating on d-c or very low-frequency a-c signals. Essentially, the maximum available output voltage varies inversely with the square of the frequency of the applied signal.

The amplidyne generator is applicable to both "open" and "closed-cycle" control. The greater field, however, is in closed-cycle-control mechanisms because of certain inherent differences between the two types, as well as the more general use

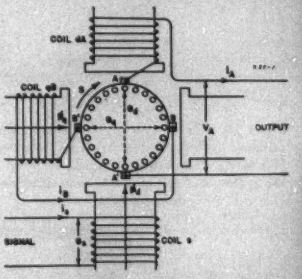

Figure 1. Essential elements and connections of the amplidyne generator

in recent years of closed-cycle control. "Open" control is that type of automatic control in which the quantity (time, voltage, displacement, and so forth) which actuates the control mechanism is essentially independent of the control operation. A simple example of this type is the automatic-starting compensator used for starting induction motors, synchronous motors, and so forth. These devices initially connect the machine terminals to a reduced voltage supply. By means of a time relay full line voltage is applied to the machine after normal speed is attained. This mechanism is a time-operated open-control device since it allows a definite time independent of acceleration for the starting period. "Closed-cycle" control is that type of automatic control in which the quantity which actuates the control mechanism is affected by the control operation. A good example of this

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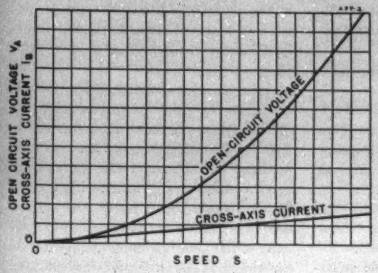
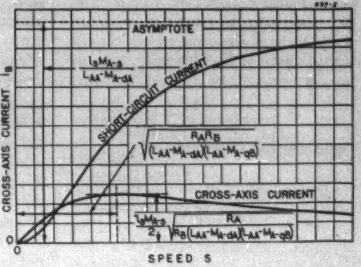


Figure 2 (left). Calculated curves illustrating the nature of the open-circuit characteristics of the amplidyne generator

Figure 3 (right). Calculated curves illustrating the nature of the short-circuit characteristics of an undercompensated amplidyne generator



type is automatic ship steering. Here, the angle between the ship compass and the hull is used to control the rudder, and this angle in turn is affected by the rudder operation.

In the first type of control the source of the controlling quantity usually has sufficient power to operate the control mechanism directly. In the second type the source of control usually is some form of measuring instrument which seldom can deliver any appreciable amount of power. Therefore, the original signal must be amplified in order that sufficient power be available to drive the control mechanism. The amplidyne generator provides a very satisfactory means of obtaining the necessary power amplification when a d-c control signal is used, and when a large amount of power is required to drive the control mechanism.

Closed-cycle-control mechanisms usually operate on the difference of two quantities, that is the difference between the desired quantity and the quantity which actually results from the output of the control mechanism. In the ideal case this difference would be zero, but this result is never obtained in practice. Comparison with the ideal, however, furnishes a standard by which the actual operation of the control mechanism may be judged.

In studies of the operation of a control mechanism the over-all behavior of the complete system including all main and control units must be analyzed, and the individual units so designed and adjusted that stable operation of the entire system is obtained. At the same time, the operation must be compared with that of the ideal in order that actual working tolerances may be kept to a satisfactory minimum. It is essential, therefore, that the operation of each individual unit, particularly in the control system, be expressible in simple quantitative terms. The load-voltage characteristic equation of the amplidyne generator (equation 14 of the appendix) defines the over-all operation of this machine and may be used in such analyses. It is valid for any type of load supplied by the generator, provided that the range of operation on the magnetization curve is sufficiently low that saturation effects are negligible. In most control applications this condition would be fulfilled, since a linear relationship between the signal and the output from the amplifying unit is usually desirable.

In instances where satisfactory operation is not attained for one reason or another, a comprehensive knowledge of the behavior of the various units comprising the control mechanism is necessary in order that proper adjustments or modifications may be made. Other characteristics of the amplidyne generator such as the variation of voltage and short-circuit current with speed and the effects of various coils on these characteristics provide this information. Overcompensation and undercompensation are necessary considerations, because these factors influence the stability of the machine. Generally speaking, overcompensation results in a higher output for the same signal input but causes inherent tendencies toward instable operation.

The essential electric elements of the amplidyne generator are an ordinary d-c armature and commutator, two complete sets of brushes spaced 90 electrical degrees apart, and windings connected as shown in Figure 1. The signal to be amplified, usually direct current, is applied to coil s. Current in this coil gives rise to a flux in the main axis of the machine, that is in the axis in line with the brushes AA'. Motion of the armature conductors in this flux generates a voltage in the cross axis, that is between the brushes BB'. Since these brushes are connected electrically, a current flows which produces a flux in the cross axis by virtue of armature reaction. The coil qB may be omitted in an actual machine but is included in the figure, since commutating poles used to secure good cross-axis commutation produce an effect on the machine constants similar to that of the coil qB. If present, this coil may be connected so as to add to or subtract from the magnetomotive force produced by the current flowing in the armature coils. The armature rotating in the cross-

Figure 5. Calculated curves illustrating the nature of the load characteristics of the amplidyne generator and the effect of different degrees of main-axis compensation on these characteristics

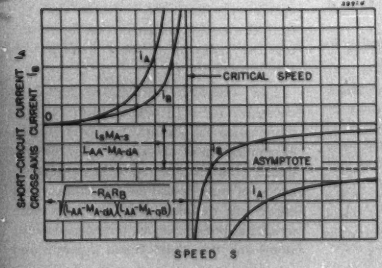
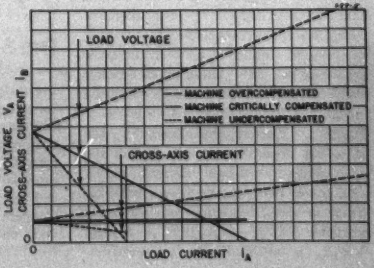


Figure 4 (left). Calculated curves illustrating the nature of the short-circuit characteristics of an overcompensated amplidyne generator

The machine is unstable even in the steady state for any speed above the critical speed



axis flux gives rise to a voltage in the main axis which appears between the brushes AA'. This is the source of the output voltage of the machine. The purpose of the coil dA is to compensate for armature reaction in the main axis.

Open-Circuit Characteristics

The open-circuit or no-load characteristics of the amplidyne generator are expressed by equations 8, 9, and 10 of the appendix. The signal current is a function only of the signal voltage and the resistance of the signal coil. The cross-axis current varies linearly with the speed, and the output voltage varies with the square of the speed. The nature of these characteristics is illustrated by the calculated curves of Figure 2. The cross-axis current and the output voltage on open circuit are independent of the number of turns in the compensating coil dA.

The magnitude of the open-circuit voltage of the machine is governed by the mutual inductance between the signal coil and the armature and by the two cross-axis constants L_{AA} and M_{A-qB}. With other factors constant, doubling the number of turns in the armature coils increases the output voltage eight times if the coil qB is not present. In order to obtain a high output voltage, the cross-axis circuit resistance must be low as this factor appears in the denominator of the open-circuit voltage equation. The voltage acting in the cross axis is usually quite small, of the order of a few volts, so that brush drop represents a considerable portion of the total cross-axis circuit resistance. It is imperative, therefore, that material of very low contact resistance be used for the cross-axis brushes.

Short-Circuit Characteristics

The short-circuit characteristics of the amplidyne generator are expressed by equations 11, 12, and 13 of the appendix. The signal current depends only upon the signal voltage and the resistance of the signal coil. The nature of the two current characteristics depends upon the degree of compensation of the machine, that is upon the relative number of turns in the compensating coil dA. These characteristics are illustrated for an undercompensated machine by the calculated curves of Figure 3. The cross-axis current i_B has an initial slope the same as that of the open-circuit cross-axis current curve. The slope, however, decreases with increase in speed becoming zero when the condition $S^2(L_{AA}-M_{A-dA})(L_{AA}-M_{A-qB}) = R_A R_B$ is satisfied. As the speed increases further, the cross-axis current decreases and approaches zero asymptotically.

The short-circuit current i_A, beginning with an initial slope of zero, increases with the speed approaching asymptotically a definite finite value which depends upon the degree of compensation of the machine. As the ratio $R_A R_B/(L_{AA}-M_{A-qB})$ is made smaller by careful design of the machine, the short-circuit current approaches more closely the asymptotical value for any given maximum speed.

The asymptotical value of the short-circuit current, as obtained from the limit of equation 13 as S becomes infinite, is given by the expression $M_{A-d}i_s/(L_{AA}-M_{A-dA})$. With the compensating coil dA connected in the usual manner with regard to polarity, the value of the asymptote becomes larger and larger as turns are added to the compensating coil. When the number of turns are such that M_{A-dA} is equal to L_{AA}, the asymptote disappears, and the short-circuit current varies directly with the square of the speed of the machine. This condition may be used to define the boundary between overcompensation and undercompensation in the main axis. If the number of turns in the compensating coil are further increased so that M_{A-dA} is greater than L_{AA}, the value of the asymptote becomes negative, and the speed-current curve has a discontinuity at the point where $S^2(M_{A-dA}-L_{AA})\times(L_{AA}-M_{A-qB}) = R_A R_B$. The operation of an overcompensated machine is stable in the steady state for speeds below the critical speed represented by this condition. At this critical speed the operation becomes unstable, and the short-circuit current increases without limit. For higher speeds, theoretically, the current reverses direction and decreases asymptotically to the value given by the asymptote expression. The curves for this condition illustrated in Figure 4 were calculated on the basis of the same constants as the curves of Figures 2 and 3 except that the value of the constant M_{A-dA} was increased approximately 20 per cent. This value represents a machine approximately six per cent overcompensated; that is, there are six per cent more turns in the compensating coil dA than those required for critical compensation as defined from the relation $L_{AA}=M_{A-dA}$.

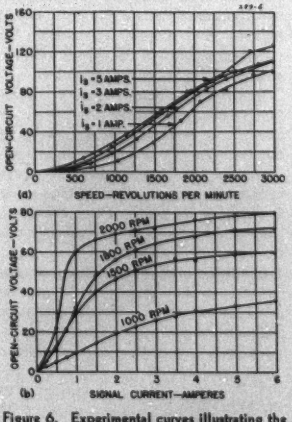


Figure 6. Experimental curves illustrating the effect of hard carbon brushes

For satisfactory operation the speed would have to be restricted to a maximum of 1,000 rpm and the signal current to 2.5 amperes. Brush drop resulting from higher speeds and signal currents causes excessive distortion as indicated by the crowding of the curves of (a) and the nonlinearity of the curves of (b). Compare with the curves of Figure 7 which were obtained from the same machine using graphite brushes

Load Characteristics

The load characteristics of the amplidyne generator are expressed by equations 14 and 15 of the appendix. For a given signal current and speed the curves are straight lines. If the machine is undercompensated, the lines are drooping, that is of negative slope, at any constant speed. If overcompensated, the lines are drooping at low speeds and are rising, that is of positive slope, at high speed. The load-voltage load-current characteristic becomes horizontal when the relationship $S^2(L_{AA}-M_{A-dA})(L_{AA}-M_{A-qB}) = -R_A R_B$ is satisfied. If the machine is critically compensated, the curve is drooping, but the slope is independent of the speed of the machine. The effect of different degrees of compensation on the load characteristics is illustrated by the curves of Figure 5, which were calculated for a three per cent overcompensated, a critically compensated, and a three per cent undercompensated machine respectively. For all three sets of curves, the speed is the same and is greater than the critical speed at which instability results for the overcompensated machine on short-circuit.

Low cross-axis circuit resistance is necessary for high output from the machine since the factor R_B appears in the denominators of all terms. If R_B is reduced to half its original value, both intercepts of the load-voltage load-current curve are doubled, and the maximum available power output is increased four times for the same signal current and

speed. The maximum available power output is equal to one-fourth the product of the two intercepts of the load-voltage load-current characteristic curve.

A critically compensated machine is stable in the steady state, regardless of the speed or the type of load. An overcompensated machine becomes unstable and builds up as a series generator for certain conditions, depending upon the speed of the machine, the degree of overcompensation, and the type of load supplied. If the machine supplies a constant impedance load, stable operation in the steady state occurs as long as the condition $(R_A+R_L)R_B > S^2(M_{A-dA}-L_{AA})\times(L_{AA}-M_{A-qB})$ is fulfilled. The resistance of the load impedance is R_L. Thus, in the practical application of an overcompensated machine, instable operation may result if the load resistance is too low or if the speed of the machine is too high.

A critically compensated or overcompensated amplidyne generator may display a form of transient instability characterized by the output voltage, and also by the output current, building up to a very high value before coming to the final steady-state value when a sudden increase of load occurs. Transients of this character arise from the magnetic coupling between the compensating coil, the main-axis armature circuit, and the signal coil. In general, the compensating coil is more closely coupled with the signal coil than is the armature, because of the air gap. For critical compensation, the compensating coil must contain a few more turns than the equivalent number of turns on the armature. Thus, a sudden change of current in the load circuit will induce a current in the signal circuit of such direction as to increase the strength of the main-axis flux. This, in turn, causes a greater output voltage and greater output current from the machine. In some cases this action may be cumulative and result in free oscillation. In order to eliminate the possibility of transients of this character, the number of turns in the compensating coil dA must be reduced to the point where the transient components of current induced in the signal coil by sudden changes in the load current give rise to effects which oppose the original change of load current. This condition is fulfilled when M_{dA-s} is less than M_{A-s}.

To obtain the maximum output for a given maximum speed and signal current, the degree of compensation of the machine should be as high as possible. In order that the condition of critical compensation may be more closely approached without introducing tendencies toward instability, the compensating coil dA should be arranged with respect to the signal coil s so as to allow a lower coefficient of coupling between the two. This coefficient of coupling theoretically should be the same as that between the compensating coil and the armature.

Experimental Data and Results

In order to check experimentally the theory and equations presented in this paper, an amplidyne generator was constructed from a General Electric type *RI*, three-horsepower, induction motor. The armature of this machine was used without modification since it was wound with a four-pole wave winding. The stator was rewound with a four-pole distributed winding, part of the slots being used for an interpole winding in order that satisfactory commutation could be obtained at the cross-axis brushes. The compensating coil dA consisted of 14 turns per coil, four coils per pole, with taps brought out so that 9, 10, 11, 12, 13, or 14 turns per coil could be used. The signal coil was wound with five turns per coil, four coils per pole. The interpole winding consisted of 50 turns surrounding each of the four stator teeth located in the cross-axis neutrals. While this design is not particularly efficient from the practical standpoint because of insufficient space for copper in the stator slots, it provides a satisfactory means for an experimental check of theory.

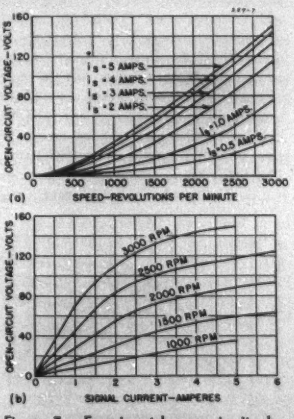


Figure 7. Experimental open-circuit characteristic curves of an amplidyne generator equipped with soft graphite brushes in the cross axis

In making adjustments for satisfactory operation of the machine, it was found that the higher taps of the compensating winding gave so much overcompensation that they could not be used. The machine would build up as a series generator to a very high value of armature current when the machine was loaded. On the highest tap the machine would oscillate at a frequency of approximately 80 cycles per second for very low values of load resistance.

Physically, the amplidyne generator may be considered a two-stage amplifier. The first stage is represented by the voltage generated in the cross-axis circuit by the flux produced in the main axis by the signal coil. The second stage is represented by the voltage generated in the output circuit by virtue of the flux established in the cross-axis circuit by the cross-axis current. When load current flows in the output circuit a component of flux, in addition to that produced by the signal coil, is produced in the main axis. This component adds to the flux of the signal coil if the machine is overcompensated and subtracts if the machine is undercompensated. Thus, an overcompensated amplidyne generator is in effect a regenerative amplifier. It is unstable if too much of the output is fed back into the first stage of the machine by virtue of too many turns in the compensating coil. On the other hand, an undercompensated amplidyne generator is a degenerative amplifier and is quite stable. For this reason the tests were made with the compensating coil dA connected with nine turns per coil, giving a slightly undercompensated machine.

Hard carbon brushes were entirely unsatisfactory, as illustrated by the curves of Figure 6, because of the comparatively low voltages generated in the cross-axis circuit. Soft graphite brushes gave very satisfactory operation, but in this case the adjustment of the interpole shunt was quite critical. Best conditions of cross-axis commutation were obtained with a diverter which would by-pass approximately ten per cent of the total cross-axis current.

The characteristics of the test machine after the necessary adjustments were made to secure satisfactory operation are illustrated by the curves of Figures 7, 8, and 9. According to theory, the curves of Figure 7a should be parabolas, while the curves of the other five figures should be straight lines. In actual operation of the machine several factors such as magnetic saturation and brush drop cause the curves to deviate from the theoretical form.

The total ampere turns acting to produce flux in the space between brushes A and B and between brushes A' and B'

(see Figure 1) is proportional to the *sum* of the ampere turns acting in the cross axis and the ampere turns acting in the main axis. The total ampere turns acting to produce flux in the space between brushes B and A' and between brushes B' and A is proportional to the *difference* between the ampere turns acting in the cross axis and the ampere turns acting in the main axis. Thus, the total flux and the degree of magnetic saturation are greater in the air gap between brushes A and B and between brushes A' and B' than between brushes B and A' and between brushes B' and A. The total voltage generated in the cross-axis circuit is proportional to the total flux distributed around the armature between brushes B and B', and the total voltage generated in the output circuit is proportional to the total flux distributed around the armature between brushes A and A'. Since the same components of flux are involved in the generation of both of these voltages, the effects of magnetic saturation appear simultaneously in both the cross-axis and main-axis circuits.

In Figure 7b, the 1,000-rpm curve is essentially linear for signal currents up to four amperes, and the 2,000-rpm curve for signal currents up to two amperes. At higher signal currents magnetic saturation caused a decrease in the machine inductances with the result that the curves fall below the points represented by the initial linear relationship.

Since the measured resistance of the cross-axis circuit was slightly greater than one ohm, the change of the resistance of the graphite brushes with current was sufficient to cause a noticeable effect. This accounts for the upward turn of the 0.5-ampere and 1.0-ampere curves of Figure 8a near 2,500 rpm. For the 2-ampere curve the effects of magnetic saturation were appreciable for speeds above 2,200 rpm (as illustrated by the corresponding curves of Figure 8b). The slight decrease in the generated cross-axis voltage at high speed due to saturation was offset by the decrease in brush resistance. The resulting curve of cross-axis current was linear.

Characteristics of the Machine From Open-Circuit and Short-Circuit Tests

In order to calculate the operating characteristics of the amplidyne generator, machine constants must be used which are valid for actual conditions of operation. The values of the constants are influenced by magnetic saturation, by brush losses and commutation, and by hysteresis and eddy current losses. Therefore, any set of constants obtained from direct measurements of the impedances or inductances must be modified to include these factors. Such modifications are difficult to make accurately, since the effects of the losses on the machine constants cannot be expressed in simple quantitative terms. The necessity for making modifications can be eliminated to a large extent if the constants of the machine are calculated from test data from open-circuit and short-circuit tests performed on the machine.

The two constants B and C are calculated from open-circuit test data in accordance with the following equations which result from equations 19 and 20 of the appendix:

$$\left.\begin{aligned} B &= i_B/Si_s \\ C &= V_A/Si_B \end{aligned}\right\} \text{ Open-circuit test data used in these equations}$$

The constants A and R_A are calculated from short-circuit test data in accordance with the following equations which result from equations 21 and 22 of the appendix:

$$\left.\begin{aligned} R_A &= CSi_B/i_A \\ A &= (Bi_s/i_A) - (R_A/CS^2) \end{aligned}\right\} \text{ Short-circuit test data used in these equations}$$

These four constants together with equations 19 to 23 are sufficient for the calculation of any of the steady-state characteristics of the amplidyne generator. The speed S in the equations above may be expressed in revolutions per minute instead of radians per second. In this case the speed S in equations 19 to 23 derived from these four constants must also be expressed in revolutions per minute.

The accuracy of this method for determining the characteristics of the amplidyne generator is shown by the curves of Figures 10 and 11, which were calculated on the basis of constants determined from open-circuit and short-circuit test data. For comparison actual test values are indicated by small circles and triangles plotted on the same axes.

In Figure 10a, the test points of the open-circuit voltage and cross-axis current curves for one-ampere signal current

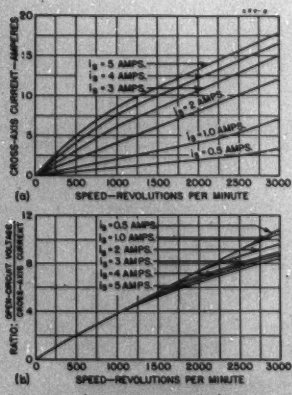


Figure 8. Open-circuit speed characteristics of the first and second stages respectively of an amplidyne generator

Nonlinearity of the curves of (b) are an indication of magnetic saturation of the machine

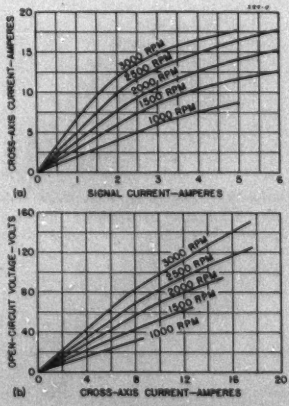


Figure 9. Open-circuit saturation curves of the first and second stages respectively of an amplidyne generator

Nonlinearity of the curves of (b) results from magnetic saturation of the machine, while nonlinearity of the curves of (a) result from magnetic saturation and brush drop at the cross-axis brushes

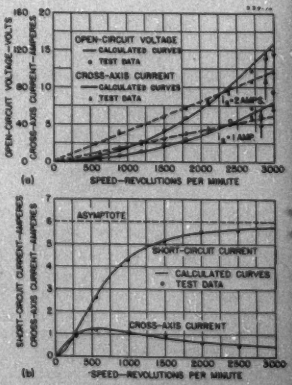


Figure 10. Comparison of calculated open-circuit and short-circuit characteristic curves with actual test data

fall above the calculated curves for speeds above 2,200 rpm. This discrepancy is due to the decrease in the resistance of the cross-axis brushes with increase in cross-axis current at the higher speeds. For the two-ampere signal current curve of cross-axis current, the change in brush resistance with current was offset by saturation, with the result that the test points agree very closely with the calculated curve. The test points of the corresponding open-circuit voltage curve fall below the calculated curve for speeds above 2,200 rpm because of saturation effects in the second stage of the machine.

Conclusions

Commutation and brush effects, particularly in the cross-axis circuit, have a very pronounced effect upon the operation of the amplidyne generator. Bad commutation and brush losses cause a considerable decrease in the available output. In order that the machine operate satisfactorily, the use of proper brush material and the realization of good commutation are imperative. To insure good commutation interpoles may be used to excellent advantage. The brushes in the cross-axis circuit must be of low resistance and produce as small a contact drop as possible.

The characteristics of the machine may be calculated on the basis of open-circuit inductances and resistances. The constants used for calculations must correspond with actual conditions of operation; but the main- and cross-axis coils may be treated as magnetically independent. The speed voltages appear in the opposite axes from the fluxes which produce them. The effects of magnetic saturation appear in both the main- and cross-axis circuits simultaneously. Saturation effects are difficult to include in calculations, because the degree of saturation changes with the speed and with the load.

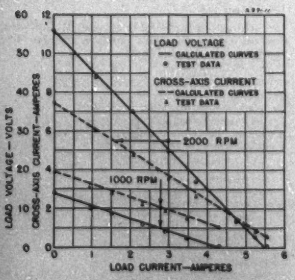


Figure 11. Comparison of calculated load characteristic curves with actual test data

Constants for the calculation of the steady-state characteristics of the amplidyne generator may be determined from open-circuit and short-circuit tests performed on the machine. This method offers the advantage that the values so obtained apply for actual conditions of operation. For purposes of design the characteristics may be predicted on the basis of the inductance coefficients, which may be obtained by the methods used for the more standard electrical machines by calculation of the various flux linkages involved. This method, however, is subject to considerable error because of the uncertainty of many factors, principally those relating to commutation, brush drop, and the associated losses.

The output load-voltage characteristic of an undercompensated machine is drooping (of negative slope) for all conditions of operation. The corresponding characteristic of an overcompensated machine may be either drooping or rising (of positive slope), depending upon the speed and the degree of overcompensation. Low speed together with a low degree of overcompensation gives a drooping characteristic which becomes horizontal and then rising if either of these two factors is sufficiently increased. A machine having a rising characteristic is unstable, even for steady-state operation, if the load resistance is less than a definite critical value which depends upon the slope of the characteristic curve.

Transient instability may result in an overcompensated or in an undercompensated machine, if the mutual inductance between the compensating coil and the signal coil is greater than the mutual inductance between the signal coil and the armature. Transient instability arising from this cause is characterized by the load current and the load voltage building up to very high values before coming to their final steady-state values when a sudden increase of load occurs. With a sudden decrease of load, the opposite effect takes place. In some instances this action may be cumulative and may result in free oscillation of the machine. If the compensating coil is arranged so that a fairly high leakage flux exists between it and the signal coil, a greater output is available from the machine without loss of stability.

The open-circuit voltage varies directly with the square of the speed, while the short-circuit current approaches asymptotically a definite value which depends upon the signal current and the design of the machine. For maximum power output and power amplification the speed should be as high as possible.

The available power output and also the power amplification become infinite for d-c operation of the machine at constant speed as the resistance of the cross-axis circuit approaches zero. As the resistance of the signal coil approaches zero, the power supplied by the signal source approaches zero, and the power amplification again becomes infinite. Since both of these resistances may be made quite low, the power amplification of an amplidyne generator operating on direct current is very high. The machine used in obtaining data for this paper gave a maximum value of approximately 300. This corresponds with an ordinary d-c generator having a field loss of one third of one per cent. By use of a specially designed stator core which would allow more copper in the signal coil and interpole windings, a power amplification of at least ten times this value could easily be obtained.

Appendix. D-C Operation of the Amplidyne Generator

If a d-c signal is applied to coil s (Figure 1), the steady-state behavior of the machine is expressed by the following equations:

$$e_s = i_s R_s \tag{1}$$

$$e_q = i_B R_B = K S \phi_q 10^{-8} \tag{2}$$

$$e_d = i_A R_A + V_A = K S \phi_q 10^{-8} \tag{3}$$

If the speed of the machine is measured in electrical radians per second, the constant K is the equivalent number of series armature turns between opposite brushes, that is the number of series turns which would give the same number of flux linkages if each of these turns linked all the flux in either axis. The expressions $K\phi_d$ and $K\phi_q$ are the total number of armature flux linkages in the main and cross axes of the machine respectively. The total flux which is effective in producing speed voltage in the output circuit, that is ϕ_d, includes the mutual flux from coils dA and s as well as the leakage flux of the armature. Likewise, the total flux which is effective in producing speed voltage in the cross-axis circuit includes the mutual flux from coil qB as well as the leakage flux of the armature. In terms of open-circuit self- and mutual inductances the flux linkages in the main and cross axes are:

$$K\phi_d = N_A \phi_d = (M_{A-s} i_s - L_{AA} i_A + M_{A-qA} i_A) 10^8 \tag{4}$$

$$K\phi_q = N_A \phi_q = (L_{AA} i_B - M_{A-qB} i_B) 10^8 \tag{5}$$

The negative sign is used before the mutual inductance M_{A-qB}, because the coil qB is assumed connected so as to compensate partially for armature reaction in the cross axis. This sign should be positive if the coil is connected the other way. Making use of these relations, equations 2 and 3 may be written:

$$i_s S M_{A-s} - i_B R_B - i_A S (L_{AA} - M_{A-qA}) = 0 \tag{6}$$

$$i_B S(L_{AA}-M_{A-qB})-i_A R_A=V_A \tag{7}$$

The open-circuit characteristics of the machine are obtained from the solution of these equations with the load current i_A equated to zero:

$$i_s=e_s/R_s \tag{8}$$

$$i_B=i_s SM_{A-s}/R_B \tag{9}$$

$$V_A=i_s S^2 M_{A-s}(L_{AA}-M_{A-qB})/R_B \tag{10}$$

The short-circuit characteristics of the machine are obtained from equations 1, 6, and 7 with the load voltage V_A equated to zero:

$$i_s=e_s/R_s \tag{11}$$

$$i_B=\frac{SM_{A-s}R_A}{S^2(L_{AA}-M_{A-dA})(L_{AA}-M_{A-qB})+R_A R_B}\,i_s \tag{12}$$

$$i_A=\frac{S^2M_{A-s}(L_{AA}-M_{A-qB})}{S^2(L_{AA}-M_{A-dA})(L_{AA}-M_{A-qB})+R_A R_B}\,i_s \tag{13}$$

If the machine is supplying a constant resistance load, the voltage V_A in equation 7 is replaced by $i_A R_L$ in which R_L is the resistance of the load. The solutions for the three currents are exactly the same as the short-circuit characteristics except that the resistance of the main-axis circuit becomes (R_A+R_L) instead of R_A. The load voltage is found from the relation $V_A=i_A R_L$ after the currents are obtained.

The load characteristics of the machine are obtained from equations 6 and 7 by elimination of i_B and V_A respectively:

$$V_A=\frac{-[S^2(L_{AA}-M_{A-dA})(L_{AA}-M_{A-qB})+R_A R_B]}{R_B}\,i_A+\frac{S^2M_{A-s}(L_{AA}-M_{A-qB})i_s}{R_B} \tag{14}$$

$$i_B=\frac{-S(L_{AA}-M_{A-dA})}{R_B}\,i_A+\frac{SM_{A-s}i_s}{R_B} \tag{15}$$

These latter two equations are valid regardless of the type of load supplied by the machine. Equation 14 expresses the relation between the three variables V_A, i_A, and i_s, and may be used to define the overall operation of the amplidyne generator in any control circuit in which it is connected, provided the machine operates low enough on the magnetization curve so that saturation effects may be neglected.

The equations given above may be simplified by the following substitutions:

$$A=(L_{AA}-M_{A-dA})/R_B \tag{16}$$

$$B=M_{A-s}/R_B \tag{17}$$

$$C=(L_{AA}-M_{A-qB}) \tag{18}$$

In terms of these constants the characteristic equations are:

Open-circuit characteristics:

$$i_B=BSi_s \tag{19}$$

$$V_A=BCS^2i_s \tag{20}$$

Short-circuit characteristics:

$$i_B=\frac{BR_AS}{ACS^2+R_A}\,i_s \tag{21}$$

$$i_A=\frac{BCS^2}{ACS^2+R_A}\,i_s \tag{22}$$

Load characteristics:

$$V_A=-(ACS^2+R_A)i_A+BCS^2i_s \tag{23}$$

$$i_B=-ASi_A+BSi_s \tag{24}$$

List of Symbols

e_d—Generated voltage in the main-axis or output circuit

e_q—Generated voltage in the cross-axis circuit

e_s—Voltage applied to the signal coil

L_{AA}—The self-inductance of the armature between either the main-axis brushes or between the cross-axis brushes

M_{A-dA}—The mutual inductance between the armature and the compensating coil dA

M_{A-qB}—The mutual inductance between the armature and the cross-axis coil qB

M_{A-s}—The mutual inductance between the armature and the signal coil s

M_{dA-s}—The mutual inductance between the compensating coil dA and the signal coil s

R_A—Resistance of the main-axis circuit internal to the machine. Includes the resistance of the armature, the main-axis brushes, and the compensating coil dA

R_B—Resistance of the cross-axis circuit. Includes the resistance of the armature, the cross-axis brushes, and the cross-axis coil qB

R_L—Resistance of the load impedance

R_s—Resistance of the signal coil s

S—Speed in electrical radians per second

V_A—Output or load voltage

ϕ_d—The total flux linking the armature in the main axis

ϕ_q—The total flux linking the armature in the cross axis

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Analysis of Short Circuits for Distribution Systems

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MEMBER AIEE

Synopsis: This paper presents a discussion and analysis of short circuits for low-voltage distribution systems. Many distribution systems are supplied from transformers connected in delta on the low-voltage side with the mid-tap of one secondary winding, or with one corner of the delta, connected to ground. As a result, short circuits on these systems often involve failure to ground, and an accurate analysis for these faults is of value. An original analysis of power-leg-to-ground and light-leg-to-ground short circuits is presented together with formulas for line-to-line and three-phase faults. A study of short circuits on the secondary circuits of single-phase transformers supplied from three-phase systems is also included, thereby giving a comprehensive treatment of distribution short circuits. The paper also includes a discussion of the effects of resistance in limiting short-circuit currents and the voltage rise of the secondary neutral above ground potential caused by transformer failure and resistance to ground.

DISTRIBUTION transformer banks supplying 240-volt three-phase and 120/240-volt single-phase loads generally have the mid-point of one secondary winding connected to ground. This is done to protect the low-voltage distribution systems against high voltage in the event of transformer failure and to provide a ground for the low-voltage systems. An accurate analysis of short circuits and related problems on these systems is important in the selection and setting of protective equipment and in reduction of personal and fire hazards. The ratings of these transformer banks are from about 6 to 1,000 kva. The most common short circuit in conduits and machines is failure to ground. In addition to the unsymmetrical conditions imposed by a fault to ground, special considerations are required, since it is assumed that the transformer secondaries are connected in delta and the ground return is furnished by a connection to the mid-point of one secondary winding. Other connections are in common use. Three-phase four-wire circuits may be supplied from transformers with the low-voltage secondary windings wye-connected with the neutral grounded, and transformers without mid-taps supplying three-phase three-wire 240 volts often have one corner of the secondary delta connected to ground. This paper presents an analysis of power-leg-to-ground and light-leg-to-ground instantaneous symmetrical short-circuit currents and a discussion of short-circuit currents on distribution systems resulting from high-voltage transformer failures. Consideration of three-phase and line-to-line low-voltage short circuits and low-voltage short circuits on single-phase distribution transformers is also included.

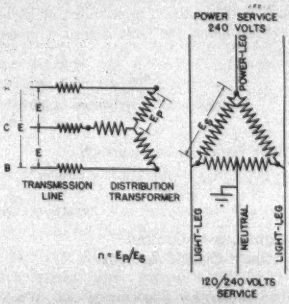

Figure 1. Typical distribution transformer with mid-point of one secondary winding grounded

The schematic diagram of Figure 1 gives the terminology and connections in common use for obtaining 240-volt three-phase three-wire and 120/240-volt single-phase three-wire services from a single transformer bank. For cases where the power load predominates, such as in industrial plants, the three transformers are ordinarily of the same capacity. Where single-phase loads predominate, for example, in rural installations, the two transformers used to furnish the power-leg are usually the same size, but they may be smaller than the third unit. In this study it is assumed that the three transformers are identical. However, in solving practical problems differences in capacity may be accurately taken into account for power-leg-to-ground short circuits, and approximations may be introduced for light-leg-to-ground faults.

Effect of Resistance in Limiting Low-Voltage Short-Circuit Currents

Although resistance may produce a negligible effect in limiting short-circuit currents on high-voltage systems, it may have a considerable effect when faults occur on low-voltage circuits.[1] It is evident that the higher the voltage, the higher are the ohmic values of equipment impedance. Therefore, impedances having about the same ohmic values regardless of voltage rating may produce a negligible effect on high-voltage short-circuit currents when in combination with high-impedance equipment, but they may be very important on low-voltage circuits when connected in series with other low-impedance apparatus.[2] For 120- or 240-volt circuits resistance is often the predominating current-limiting factor, and omission of it (in the interest of simplicity) may lead to serious error. The importance of resistance is illustrated in Figure 2, wherein line-to-ground fault current* is plotted against ground or fault resistance for a few selected voltages. Resistance is included in both analysis and examples of the present discussion.

Power-Leg-to-Ground Short-Circuit Analysis

Transformers Connected in Wye-Delta

It is apparent from inspection of Figure 3, that a power-leg-to-ground short circuit is a special type of single-phase fault. The voltage effective in producing the fault current is $\sqrt{3}E_s/2$. The fault current is equal to the sum of two equal low-voltage secondary currents which are inphase with each other. Neglecting the effects of load and transformer exciting current, the instantaneous symmetrical secondary current is given by:

$$I_s = \frac{\sqrt{3}E_s/2}{z_{PL} + z_{(S-P)} + 0.5z_{(S/2-S/2)} + 2z}$$

in which

E_s = the voltage of the secondary winding on open circuit, in volts

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* Refer to standard references for analysis of ordinary unsymmetrical short circuits (for example, reference 3 or 4).

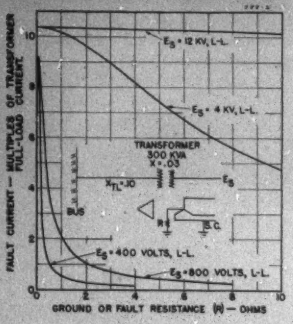


Figure 2. Effect of resistance in limiting short-circuit currents

z_{TL} = the impedance of the transmission line and other series equipment in ohms referred to the secondary voltage

$z_{(s-p)}$ = the impedance of the low-voltage secondary winding to the high-voltage primary winding in ohms (see Figure 3C)

$z_{(s/2-s/2)}$ = the impedance of one-half the low-voltage secondary winding to the other one-half low-voltage secondary winding in ohms (see Figure 3C)

z = The impedance of the external low-voltage circuit to fault, including arc, conductor, and conduit impedances, the resistance to ground, and the impedance of the ground return circuit in ohms

The fault current is:

$$I_F = 2I_s = \frac{\sqrt{3}E_s}{z_{TL}+z_{(s-p)}+0.5z_{(s/2-s/2)}+2z} \quad (1)$$

Let

E = the transmission-system voltage line-to-line, in volts

$n = E_p/E_s = E/\sqrt{3}E_s$, the transformer turn ratio

Then

$$E_s = E/n\sqrt{3}$$

and

$$I_F = \frac{E/n}{[Z_{TL}+Z_{(P-S)}]/n^2+0.5z_{(s/2-s/2)}+2z} \quad (2)$$

where

Z_{TL} = the impedance of the transmission system in high-voltage ohms. This assumes that the reactance of one wire to neutral is the same for both single-phase and three-phase balanced currents. This is true for circuits with equilateral spacing or completely transposed circuits. It is unlikely that the distribution feeder would be either equilaterally spaced or completely transposed between the source and a particular transformer installation, and for greatest accuracy the actual single-phase reactance between the two high-voltage primary line conductors carrying current should be used

$Z_{(P-S)}$ = the impedance of the high-voltage primary winding to the low-voltage secondary winding in high-voltage ohms. See Figure 3C.

The primary line currents are obtained by inspection of Figure 3B:

$$I_A = I_B = I_s/n = I_F/2n, \text{ and } I_C = 0 \quad (3)$$

TRANSFORMERS CONNECTED IN DELTA-DELTA

The analysis for the case in which the transformers are connected in delta-delta is similar to that of the preceding derivation with the exception of the modifications required due to the high-voltage delta connection. See Figure 4.

$$I_F = 2I_s = \frac{\sqrt{3}E_s}{3z_{TL}+z_{(s-p)}+0.5z_{(s/2-s/2)}+2z} \quad (4)$$

For this case $n = E_p/E_s = E/E_s$. In terms of the transmission voltage and actual transmission impedances in high-voltage ohms, the fault current is given by

$$I_F = \frac{\sqrt{3}E/n}{[3Z_{TL}+Z_{(P-S)}]/n^2+0.5z_{(s/2-s/2)}+2z} \quad (5)$$

From inspection of Figure 4B

$$I_B = I_C = I_s/n = I_F/2n, \text{ and } I_A = 2I_B = I_F/n \quad (6)$$

Light-Leg-to-Ground Short-Circuit Analysis

TRANSFORMERS CONNECTED IN WYE-DELTA

The light-leg-to-ground short-circuit analysis is developed from the method of symmetrical components as follows: The schematic diagrams of Figure 5 are based on the assumption that the system is entirely symmetrical. The dissymetry imposed by the terminal conditions which represent this type of fault is inserted in the analysis at the appropriate point.

Let

$n = E_p/E_s = E/\sqrt{3}E_s$, the transformer turn ratio

z_{TL}' = the impedance of the transmission line and other series equipment in ohms referred to one-half the secondary voltage, that is,

$$z_{TL}' = Z_{TL}\Big/\left[\frac{E_p}{E_s/2}\right]^2 = Z_{TL}/(2n)^2$$ where

Z_{TL} = the impedance of the transmission line and other series equipment in high-voltage ohms

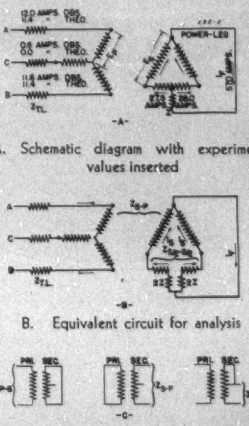
$z_{(s/2-p)}$ = the impedance of one-half the low-voltage winding to the high-voltage primary winding in ohms, and

$z_{(s/2-p)} = Z_{(p-s/2)}/(2n)$*

$z_{(s/2-s)}$ = the impedance of one-half the low-voltage winding to the entire low-voltage winding in ohms (see Figure 5D)

z = the impedance of the external low-voltage circuit to fault, including arc, conductor, and conduit impedances, the resistance to ground, and the impedance of the ground return circuit, in ohms

The positive- and negative-sequence impedances to fault are obtained from inspection of Figure 5B. All impedances are actual ohms, or expressed in ohms referred to one-half the secondary voltage



A. Schematic diagram with experimental values inserted

B. Equivalent circuit for analysis

C. Determination of transformer impedances

Figure 3 Power-leg-to-ground short-circuit analysis

Transformers connected in wye-delta

on open circuit. Z_{1F} is taken equal to Z_{1F} for determination of instantaneous symmetrical short-circuit currents. The proper generator impedances may be included in the term Z_{TL} when transient or sustained currents are desired.

The positive-sequence impedance to fault is

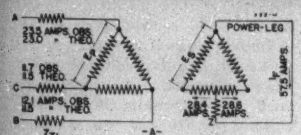
$$Z_{1F} = z_{TL}' + z_{(s/2-p)} + z$$

The zero-sequence impedance to fault is obtained from Figure 5C.:

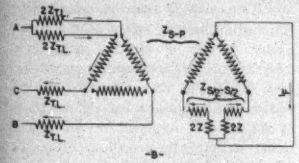
$$Z_{0F} = z_{(s/2-s)} + z$$

The equations for a line-to-ground

* The first subscript denotes the winding upon which the impedance measurements are made, or the side to which they are referred. The second subscript refers to the winding short-circuited for the impedance test. See Figure 5D.



A. Schematic diagram with experimental values inserted



B. Equivalent circuit for analysis

Figure 4. Power-leg-to-ground short-circuit analysis

Transformers connected in delta-delta

short circuit are (see reference 3 or 4 for details):

$$I_1 = I_3 = I_0 = I_F/3, \text{ and } I_F = \frac{3E}{Z_{1F} + Z_{2F} + Z_{0F}}$$

The voltage effective in producing fault current is $E_a/2$. Substituting the above expressions for the impedance to fault and the voltage effective in producing the fault current gives

$$I_F = \frac{3E_a/2}{2|z_{TL}' + z_{(S/2-P)}| + z_{(S/2-S)} + 3z} \quad (7)$$

In terms of the transmission voltage and actual transmission impedances in high-voltage ohms, the above becomes

$$I_F = \frac{\sqrt{3}E/2n}{2|Z_{TL} + Z_{(P-S/2)}|/(2n)^2 + z_{(S/2-S)} + 3z} \quad (8)$$

The primary currents are obtained from inspection of Figure 6:

$$I_C = (I_1 + I_3)/2n = 2/3(I_F/2n) = I_F/3n, \text{ and}$$
$$I_A = I_B = I_F/6n \quad (9)$$

Transformers Connected in Delta-Delta

The analysis for the case in which the transformers are connected in delta-delta is similar to the foregoing with exceptions which are apparent from inspection of Figures 7 and 8.

$$Z_{1F} = Z_{2F} = z_{TL}' + z_{(S/2-P)} + z$$

For this case

$$z_{TL}' = Z_{TL} \Big/ \left[\frac{E_P/\sqrt{3}}{E_a/2}\right]^2 = 3Z_{TL}/(2n)^2$$

$$Z_{0F} = z_{(S/2-S-P)} + z$$

in which

$z_{(S/2-S-P)}$ = the impedance of one-half the low-voltage secondary winding to the entire low-voltage winding and high-voltage winding in ohms. See Figure 7D.

Following the procedure of the previous derivation:

$$I_F = \frac{3E_a/2}{2|z_{TL}' + z_{(S/2-P)}| + z_{(S/2-S-P)} + 3z} \quad (10)$$

Or, in terms of the transmission voltage and actual transmission impedances in high-voltage ohms

$$I_F = \frac{3E/2n}{2[3.Z_{TL} + Z_{(P-S/2)}]/(2n)^2 + z_{(S/2-S-P)} + 3z} \quad (11)$$

The primary line currents are obtained from inspection of Figure 8. The zero-sequence currents circulate in both delta-connected windings, and the relative division could be worked out by using the methods developed for analyzing three-winding transformers. However, since the zero-sequence currents cannot pass from the delta into the high-voltage lines, this refinement is not necessary, and the line currents are determined directly from the positive- and negative-sequence currents as indicated in the figure.

$$I_B = I_C = I_F/2n, \text{ and } I_A = 0 \quad (12)$$

Three-Phase Short-Circuit Analysis

Transformers Connected in Delta on Low-Voltage Side

Although three-phase short circuits are of infrequent occurrence on distribution circuits, they occasionally occur on open bus structures or in other equivalent locations. The fundamental equation for three-phase short-circuit current is

$$I_{3\phi} = \frac{E_a/\sqrt{3}}{z_{TL}'' + z_{(S-P)}' + z'} \quad (13)$$

in which

z_{TL}'' = the impedance of the transmission line and other series equipment in ohms referred to the secondary voltage to neutral. For transformers connected in wye-delta

$$z_{TL}'' = Z_{TL} \Big/ \left[\frac{E_P}{E_a/\sqrt{3}}\right]^2 = Z_{TL}/3n^2$$

For transformers connected in delta-delta

$$z_{TL}'' = Z_{TL} \Big/ \left[\frac{E_P/\sqrt{3}}{E_a/\sqrt{3}}\right]^2 = Z_{TL}/n^2$$

$z_{(S-P)}'$ = $z_{(S-P)}/3$, the equivalent wye, or line-to-neutral impedance of the transformer bank, in low-voltage ohms.

z' = the line-to-neutral impedance of the external circuit to fault in low-voltage ohms including conductor impedance and fault impedance, that is, the impedance of one of three assumed equal arcs to their common meeting point.

Line-to-Line Short-Circuit Analysis

Transformers Connected in Delta on Low-Voltage Side

Line-to-line short circuits frequently occur on exposed wires and in open bus structures. This type of fault is probably most frequent on distribution systems where one corner of the secondary delta is connected to ground. Analysis is made by using the method of symmetrical components.[3,4] In terms of the open-circuit secondary voltage, the low-voltage fault current is

$$I_{L-L} = \frac{E_a}{2[z_{TL}'' + z_{(S-P)}'] + z} \quad (14)$$

in which the quantities have been previously defined. For this case z equals the total external impedance of the external circuit to fault in low-voltage ohms (in contrast to z' used for the three-phase analysis).

Short Circuits on Single-Phase Transformer Secondary Circuits

Transformers Supplied From Two High-Voltage Lines

The problem of determining short-circuit currents on single-phase transformer secondary circuits is so important that it deserves mention. If the transformer and total external impedance to fault is referred to the high-voltage side, the equation is obtained from elementary methods by inspection:

$$I_{HT1\phi} = \frac{E}{2Z_{TL} + Z_{(P-S)} + Z} \quad (15)$$

in which

$Z = n^2z$, the impedance of the external circuit to fault in equivalent high-voltage ohms

Or, the low-voltage secondary current equals:

$$I_F = \frac{E_a}{2Z_{TL}/n^2 + z_{(S-P)} + z} \quad (16)$$

Equations 15 and 16 give correct results for symmetrical subtransient fault currents. The line-to-line fault analysis developed by using the method of symmetrical components is a better approach from the strictly technical viewpoint. This gives the same equations but has the advantage that the proper generator constants may be included in the transmission-system impedance term and

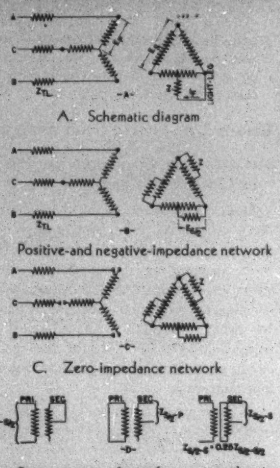


Figure 5. Light-leg-to-ground short-circuit analysis

Transformers connected in wye-delta

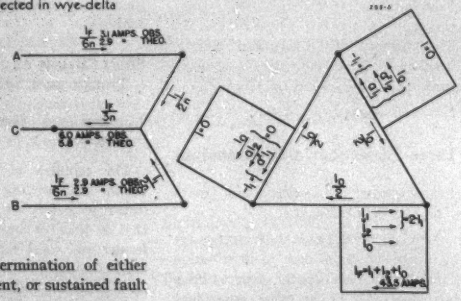


Figure 6. Detailed current distribution for a light-leg-to-ground short circuit

Transformers connected in wye-delta. Experimental values inserted

thereby permit determination of either subtransient, transient, or sustained fault current.

Transformers Supplied From One High-Voltage Line and Neutral

Analysis for this case is similar to the preceding analysis, and from the method of symmetrical components

$$I_{RT\phi}=\frac{3E/\sqrt{3}}{2Z_{TL}+Z_{0TL}+3Z_{(P-S)}+3Z} \qquad (17)$$

or the low-voltage secondary current equals

$$I_y=\frac{3E_y}{(2Z_{TL}+Z_{0TL})/n^2+3z_{(S-P)}+3z} \qquad (18)$$

in which Z_{0TL} = the zero-sequence impedance of the transmission system in high-voltage ohms.

The equations for line-to-ground faults on three-wire systems supplied from single-phase transformers having the mid-tap of the low-voltage secondary winding connected to ground are the same as the above with the following modifications: The voltage effective in producing short-circuit current is now $E_y/2$, the ratio of transformation is $2n$, and the transformer impedance is $z_{(S-P)}$.

Short-Circuit Currents on Distribution Systems Resulting From High-Voltage Transformer Failures

During the initial stages of an internal failure between the high-voltage and low-voltage windings of a transformer, that is, before any of the conductors have been opened due to arcing, the high-voltage fault current flowing through the low-voltage secondary windings induces compensating currents in the high-voltage windings which circulate back through the high-voltage circuits. Also, under these conditions the transformer saturates because of high-voltage impressed on the low-voltage windings. Saturation neglected the requirement of equal and opposing ampere turns is met, and the current limiting effect of the transformer is due to leakage impedance. Actually, because of saturation, the effective impedance may be somewhat less than the leakage impedance. For purposes of illustration consider a three-phase distribution transformer supplied from a transmission line of reasonable length and assume that short circuits occur between each high-voltage terminal and the corresponding low-voltage terminal. The impedance limiting the fault current is equal to the transmission-system impedance up to the transformer terminals in high-voltage ohms, plus the impedance of the transformer in low-voltage ohms. Thus, the additional impedance opposing the high-voltage short-circuit current flowing in the secondary winding equals the transformer impedance in high-voltage ohms divided by the ratio of transformation squared (that is, n^2).

For most practical distribution systems n^2 is large, and the additional current-limiting effect due to the transformer is small. For 2,400 delta 240-volt transformers $n^2=100$, and the additional impedance is one per cent of the transformer leakage impedance (saturation neglected).

Where the windings have been opened, and compensating currents cannot flow, the current-limiting effect of the transformer is due to exciting impedance. Very high saturation results, and it has been suggested that the exciting impedance may approach leakage reactance in magnitude. Analysis for this case is similar to that in the preceding paragraph. The saturated exciting impedance in high-voltage ohms is reduced by the square of the turn ratio, and the effect of the transformer may be neglected as a first approximation.

For unsymmetrical transformer failures, such as a breakdown near the end turns or between the high- and low-voltage bushings, the effect of transformer impedance is likewise small. The voltage effective in producing the fault current equals the vector sum of the voltage of the high-voltage system and the induced voltage of the secondary winding. In cases where the ratio of transformation is small, this effect may

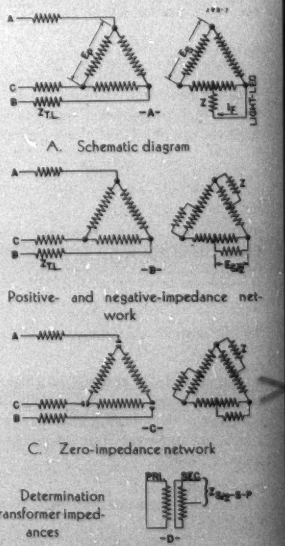

A. Schematic diagram
B. Positive- and negative-impedance network
C. Zero-impedance network
D. Determination of transformer impedances

Figure 7. Light-leg-to-ground short-circuit analysis

Transformers connected in delta-delta

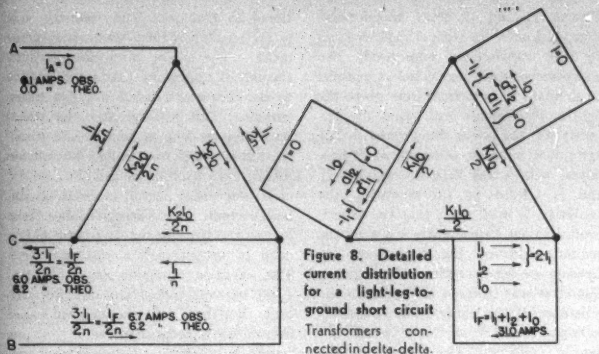


Figure 8. Detailed current distribution for a light-leg-to-ground short circuit

Transformers connected in delta-delta. Experimental values inserted

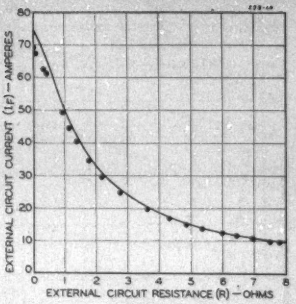


Figure 10. Power-leg-to-neutral experimental short circuits

Transformers connected in delta-delta

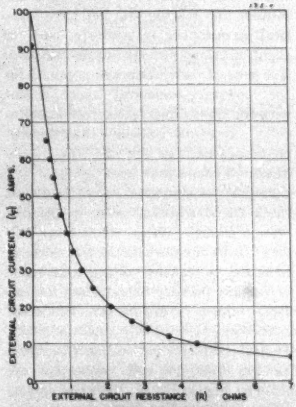


Figure 9. Power-leg-to-neutral experimental short circuits

Transformers connected in wye-delta

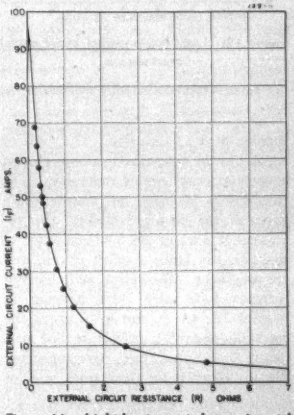


Figure 11. Light-leg-to-neutral experimental short circuits

Transformers connected in wye-delta

be important. However, for cases where the ratio is 10/1 or greater, this effect is also small and may be neglected for approximate work. An internal failure between the windings introduces additional complications, but it is unlikely that the fault current would be greater than that caused by breakdown near the extremities of the windings. Since the effects due to the transformer are relatively small, they may be neglected in estimating the high-voltage short-circuit current flowing to ground in low-voltage distribution circuits due to high-voltage transformer failures. Figure 13 gives a few of the laboratory connections used in the study of high-voltage transformer failures. The arrows represent the detailed current distribution and indicate the compensating primary currents induced by the high-voltage fault current flowing in the low-voltage secondary windings.

It is believed that the total high-voltage short-circuit current produced in low-voltage distribution circuits due to a distribution transformer failure can be determined with an accuracy sufficient for most practical purposes by neglecting the effects of the transformer itself. Additional impedances, such as the resistance of ground return circuit, must be included. It is obvious that the errors due to the approximation decrease as the impedance of the transmission system up to the transformer is increased, and conversely. It is believed this procedure is satisfactory for cases in which the feeder impedance is at least equal to 50 per cent of the transformer leakage impedance in high-voltage ohms. This analysis permits study of the effects of grounding resistances for distribution systems. It gives an approximate method of estimating the voltage to which a distribution system may rise above ground because of transformer failure, and it is important in the study of protective measures and shock hazard. Experience shows that the number of high-voltage failures in modern distribution transformers are relatively small in comparison to the number in service. However, breakdowns occasionally occur, and a mathematical approach to the problem is of value.

The total fault current in the low-voltage distribution circuit due to a high-voltage transformer breakdown is obtained from the conventional line-to-ground analysis, neglecting the effect of the transformer:

$$I_g = \frac{\sqrt{3}E}{2Z_{TL} + Z_{0TL} + 3z} \qquad (19)$$

The voltage rise of the secondary neutral above ground potential due to this fault current flowing through the impedance to ground equals:

$$E_{LT\ \text{neutral}} = \frac{\sqrt{3}Ez}{2Z_{TL} + Z_{0TL} + 3z} \qquad (20)$$

in which z represents the grounding impedance (that is, resistance of driven ground in ohms), and other quantities as defined previously.

Experimental Results

Experiments were made on a laboratory model consisting of three reactors connected to simulate a short transmission line and four ten-kilovolt-ampere transformers having two tapped primary and secondary windings, rated 500/100 volts. The experimental points and theoretical curves for power-leg-to-neutral and light-leg-to-neutral short circuits are given in

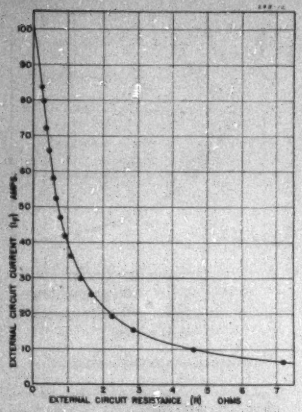


Figure 12. Light-leg-to-neutral experimental short circuits

Transformers connected in delta-delta

Figures 9 to 12 inclusive. The fault or current in the external circuit was plotted against external circuit resistance. The calculations included all known resistances of the circuit, including the resistance of a water-box load connected to simulate the fault, conduit return, and arc resistance. Theoretical and observed currents have also been inserted in Figures 3A, 4A, 6, and 8, to check the determination of high-voltage line currents. The transformers were connected 500 to 200 volts for these tests, and for Figures 11 and 12 three transformers were used. For the tests of Figures 9 and 10 four transformers were used; two transformers were connected in parallel to simulate the practical case where the lighting transformer had twice the capacity of the power transformers. The agreement between observed and theoretical values was believed satisfactory and is offered as substantiating the analysis. It was noted that the experimental values were slightly less than the computed curves, the discrepancy increasing for smaller values of resistance. The error was believed to be due to the resistance of the many leads and split-terminal socket connections which obviously could not be included in the analysis, to the fact that the system was not entirely symmetrical since the transformers and reactors did not have identical impedances respectively, and to slight unbalances of the supply voltages. The poorest correlation was obtained for the power-leg-to-neutral short circuit with the transformers connected in delta-delta. It should be noted that the discrepancies were on the safe side, as the measured values were low.

Several experiments were made to check the conclusions given in the discussion of high-voltage transformer failures. Short circuits with the transformers energized at reduced voltage were made to simulate primary to secondary failures using three transformers connected 1,000/100, 1,000/200, and 500/500. Typical results for various fault locations for the 1,000/100-volt connection are given in Figure 13. If the winding currents are multiplied by factors proportional to the turn ratio, primary and secondary ampere turns are in close agreement. The slight discrepancies from theoretical values are attributed largely to the effects of saturation and exciting current. This substantiates the statement that as long as compensating currents flow, transformer leakage impedance rather than exciting impedance, is the most important factor in limiting the fault current. As was expected, the effects due to the transformer decreased as the ratio of transformation was increased. The greatest observed error for the 1,000/100-volt connection was five per cent. For these tests the artificial transmission-line impedance was equal to 43 per cent of the transformer leakage impedance, and the ratio of Z_{0TL} to Z_{1TL} was varied between 1.0 and 5.5/1. From this it was concluded that the effects of the transformer may be neglected in approximate determination of the total short-circuit current in low-voltage circuits of practical distribution circuits because of high-voltage transformer failures for ratios of transformation of 10/1 or greater.

Figure 13. Study of effect of transformer in limiting short-circuit current for typical high-voltage transformer breakdowns

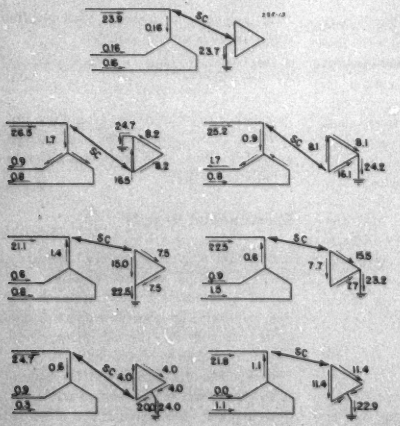
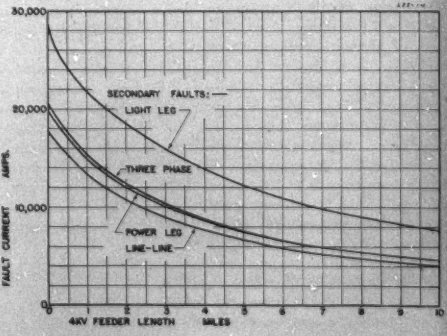


Figure 14. Short-circuit currents for 300-kva, 2,400-wye/240-120-volt transformer and four-kilovolt feeder

Fault resistance assumed zero



Application

For purposes of illustration, the results of this investigation were applied to a typical installation consisting of three 100-kva 2,400/240−120-volt distribution transformers supplied from an infinite bus over a four-kilovolt feeder. The feeder was three-conductor 4/0 copper having the common horizontal spacing of 23–30–53 inches, and $Z_{TL}=0.303+j0.622$ ohm per mile. It was assumed that $X_{0TL}=3.5X_{TL}$. The following constants were obtained from tests on one 100-kva unit.

$z_{(S-P)}$ $=0.00691+j0.01895$ ohm or $0.012+j0.0329$ per unit

$z_{(S/2-P)}$ $=0.00277+j0.00528$ ohm or $0.01925+j0.0366$ per unit

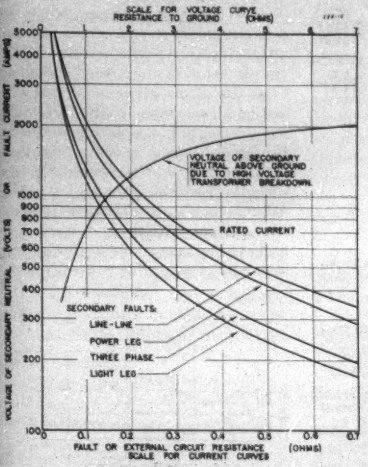


Figure 15. Short-circuit currents and voltage of secondary neutral for 300-kva 2,400 - wye / 240-120-volt transformer and 2.5 miles of four-kilovolt feeder

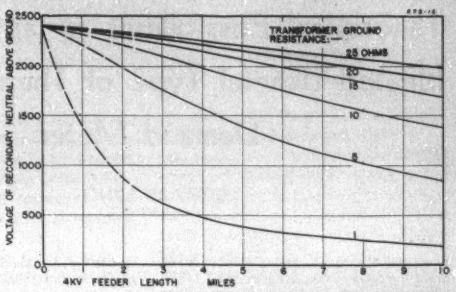


Figure 16. Voltage of secondary neutral above ground due to high-voltage transformer breakdown for 300-kva 2,400-wye/240-120-volt transformer and four-kilovolt feeder

$z_{(s/2-s/2)} = 0.00355 + j$ nil ohm or
$0.0246 + j0.000$ per unit

The transformers were assumed connected in wye-delta with the mid-point of one secondary winding connected to a ground having a variable resistance (R) ohms.

Figure 14 gives results for three-phase line-to-line power-leg-to-ground and light-leg-to-ground short circuits for various lengths of feeder up to ten miles. The fault or ground resistance was assumed zero for this case. It was noted that the light-leg-to-ground fault developed the greatest current, whereas the three-phase and power-leg short-circuit currents were approximately equal. Line-to-line short-circuit currents were the smallest and were equal to the three-phase value multiplied by 0.866.

The effects of fault resistance and resistance to ground are shown in Figure 15. For this case the feeder length was assumed to be $2^1/_2$ miles, and the fault currents were determined for external circuit resistances of 0 to 0.7 ohm. The power-leg-to-ground fault current decreased less rapidly than the light-leg fault current, the latter decreasing from its predominating value for zero resistance to values consistently below that of the other curves. It was interesting to note that if the line-to-line short-circuit current values are sketched in as a function of one-half the fault resistance, the curve practically coincides with the light-leg fault-current curve over the range covered in the figure. The important point brought out by the curves is the large current-limiting effect due to relatively small values of resistance.

The relatively large effect of small impedances in limiting low-voltage short-circuit currents has economic importance. The impedance of current transformers, resistance of joints, and the reactance due to bends in busses and connections may result in a material decrease in the interrupting duty of auxiliary circuit breakers or fuses in comparison with the main circuit breaker. Consideration of these factors in choosing the location of circuit breakers may point to improvements in plant layout with significant savings for large capacity low-voltage installations. Another aspect of this problem concerns the positive operation of circuit breakers or fuses. The protective devices would probably be set to clear for 150 to 250 per cent rated current. Entering the curves with these current values indicates that an external circuit resistance in excess of only 0.06 to 0.10 ohm would prevent proper clearing of faults. The advantage of several subfeeders with low trip values instead of one or two main circuits with high trip values or large fuses is self evident. In cases where high current-rating fuses are required, some form of ground protection (at the main circuit breaker) may be desirable.

The curve showing voltage rise of the low-voltage neutral above ground, due to a high-voltage transformer breakdown, was computed for resistances to ground of 0 to 7.0 ohms. It was found that the fault current would be limited to the rated low-voltage current of the transformer for a ground resistance of about 1.0 ohm. Hence, it was concluded that most transformer failures would be cleared only by the protective devices on the high-voltage side. During the time required to actuate the protective device, the voltage of the distribution system will be subjected to relatively high potential above ground. For example, the voltage above ground reaches 1,500 volts (the minimum dielectric strength of code rubber when new) for a ground resistance of three ohms, whereas a grounding resistance of five to seven ohms provides small protection indeed. The voltage rise of the secondary neutral above ground due to transformer failure for various resistances to ground is plotted as a function of four-kilovolt feeder length in Figure 16.

The results of the study emphasize the importance of securing low resistance to ground and low return-circuit resistances for distribution systems. It is realized that it is often difficult if not impossible to obtain driven or buried grounds having resistances low enough to provide satisfactory protection for low-voltage distribution circuits. This is particularly important for 240-volt three-phase three-wire installations where the mid-tap of one transformer is grounded and the neutral is not run into the plant. The author knows of one such installation consisting of a large transformer bank supplied over a regulated four-kilovolt feeder only a relatively short distance from the substation. The single driven ground at the transformer structure measured about 100 ohms. Although the plant conduits and equipment were apparently well grounded to the water system, little protection was actually afforded against either transformer breakdown or short circuits involving a ground return within the plant. Although the above remarks refer to the examples chosen for study, somewhat similar conclusions might result from analysis of many commercial installations.

Theoretical Possibilities in an Internally Heated Bimetal Type of Thermal Watt-Demand Meter

EDWARD LYNCH
MEMBER AIEE

Synopsis: There are two generally recognized methods of measuring demand. The block-interval type has been used extensively where great accuracy is desirable, a simple explanation necessary, and a quick testing method essential, but the "logarithmic" type has received increased attention in recent years, and a greater dissemination of knowledge of its characteristics is desirable.

A mathematical expression for "logarithmic" average is given which can apply to a variable load as well as to a uniform load. It is shown that a meter with a simple exponential time-deflection characteristic will indicate this "logarithmic" average, but that meters with characteristics obtainable in present commercial thermal meters will theoretically differ from it except when used with certain loads.

The accuracy of commercial meters has increased in recent years. So besides indicating that the various types of characteristics available in commercial meters have apparently been satisfactory on normally encountered loads, it is shown that sturdiness and high torques are desirable features to sustain these accuracies.

The internally heated thermal watt-demand principle is discussed, and the conclusion is reached that by its use high torque can be obtained using the time tested bimetal type of meter. In addition, the rapid diffusion of heat in the bimetal where it is generated theoretically allows shorter "heat-up" time when the meter is being tested and results in a time-deflection characteristic much closer to the ideal simple exponential.

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DEMAND measurements when combined with watt-hour-meter readings have been recognized as giving a practical basis for electricity charges.[1,2] In the United States demand meters operating on the block-interval principle have been extensively used, and their operating principle and characteristics are well understood.

There is another recognized method of measuring demand which has been used to a limited extent for the same purpose. It is the method utilized by thermal demand meters, and the resulting indication has been called the "logarithmic average" demand. A general explanation of meter design considerations which enter into this demand indication and the operating characteristics which they affect will be covered in the following discussion.

Time Deflection Characteristic

The block-interval meter indicates continual arithmetic average maximum demand. The thermal meter obtains its average in a different manner, and it indicates a slightly different quantity which can be designated as continuous logarithmic average maximum demand. On a constant load its reading changes rapidly at first and then more slowly until, in the case of a meter which reaches 90 per cent of its indication in 15 minutes, which by definition makes it a 15-minute demand interval meter, it would be within about one per cent of its ultimate in 30 minutes. From this characteristic we see that any load on the meter during the 30 preceding minutes may have a readable influence on the demand pointer indication, but that the longer time that has elapsed, the less effect this load has on the reading. The indicating pointer on these meters is therefore continuously changing its position as load changes occur according to what has been called a "logarithmic" average.

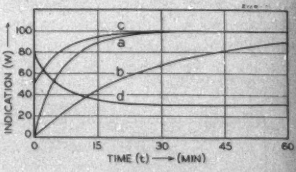

Figure 1. Curves of $W = W_i(1-\epsilon^{-kt}) + W_0\epsilon^{-kt}$

	W_i	W_0	K
a	100	0	0.1535
b	100	0	0.0384
c	100	50	0.1535
d	30	80	0.1535

This average for a theoretical meter can be expressed as follows (see appendix B):

$$W = k\int_{-\infty}^{t} we^{-k(t-t_1)}dt_1 \qquad (1)$$

where

W = instantaneous deflection of pointer
k = a design constant
w = load (which may vary with time)
t = time at which deflection is W
t_1 = time at which load is w

On constant loads after about three demand intervals this "logarithmic" average is identical with the arithmetic average as given by a block-interval type of meter.

This study would hardly be complete without one or two constructive suggestions. The goal must be as low a resistance to ground as possible. The resistances of the ground circuit must be maintained sufficiently low to insure positive operation of the protective devices in case of transformer failure. In addition, it would appear that considerable protection would result if, in addition to providing the best ground that can be reasonably obtained at the transformer installation, the low-voltage neutral be carried along with the phase wires (regardless of whether or not it is to be used for power) and connected to the plant conduit system and grounded as effectively as possible on the customer's premises. The common neutral system of grounding would appear to provide an alternate method of accomplishing the same result.

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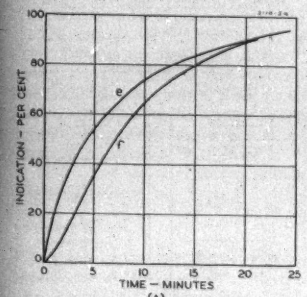
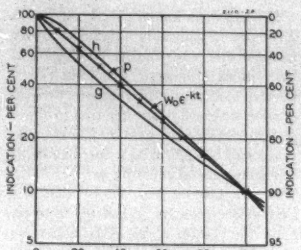
Simple Exponential Is Ideal

However, time-deflection characteristics of commercial thermal meters are not identical, and they differ from the characteristics of block-interval meters so that on fluctuating loads they can theoretically give slightly different readings. The following discussion of theoretical and practical time-deflection curves will indicate the desirability of a simple exponential characteristic for the thermal meter.

Figure 1 shows typical theoretical time-indication characteristics of thermal meters when a constant load is applied. Curves *a* and *b* differ by the fact that the demand interval or time to reach 90 per cent indication is 15 minutes (k is 0.1535)



A. Load cut to zero after equilibrium temperature is reached



B. Constant load applied from zero

Figure 2. Time-indication curves of typical thermal watt-demand meters

for *a*, and 60 minutes (k is 0.0384) for *b*. Curves *c* and *d* have 15-minute demand intervals but start with an initial indication. Each curve can be expressed by the "exponential" equation:

$$W = W_1(1-\epsilon^{-kt}) + W_0\epsilon^{-kt} \qquad (2)$$

(See appendix A)

where

W = instantaneous deflection of pointer
W_0 = deflection of pointer at zero time
W_1 = ultimate deflection for load involved
$\epsilon = 2.718$
k = a design constant
t = time

(W, W_0, W_1 must be expressed in the same units, and k must be in units the reciprocal of the units for t.)

The well-known expressions $W = W_0\epsilon^{-kt}$ and $W = W_1(1-\epsilon^{-kt})$ for the transient return of the indication to zero when power is cut off, and the rise to ultimate deflection when a constant load is applied from zero deflection, can be seen to be special cases of the above more general equation. Equation 2 holds for conditions of constant applied load, whether or not the indication starts or ends at zero, and whether the indication increases or decreases. It is interesting to note that the instantaneous deflection is equivalent to the sum of two hypothetical indications, one of which starts at zero and rises to the ultimate deflection of the meter, and the other of which starts at the initial indication of the meter and reduces to zero, both following the locus given by equation 2.

It is also interesting to note that k, which determines the demand interval has a dimension equivalent to the reciprocal of time and is a function of the heat insulation of the heated parts (increasing as the insulation decreases), and a function as well of the heat capacity of the heated masses (increasing as the capacity decreases). This same k represents in magnitude the reciprocal of the time that would be necessary to attain proper deflection if there were no heat escape. It also represents the reciprocal of the time necessary to accomplish a change in indication represented by the following fraction of the total change:

The fraction is:

$$\left(1-\frac{1}{\epsilon}\right) = 0.632 \text{ approximately}$$

If the load varies at a uniform rate (see appendix B), either increasing or decreasing, k has further physical significance because $1/k$ represents the time between the arrival at some particular watt load and the indication of that load by the meter, providing the rate has been uniform long enough (three demand intervals) for this time lag to become essentially constant. This time lag is independent of the rate of change of watts and the meter demand interval is directly proportional to it if we consider simple exponential characteristics.

Time-Deflection Curves in Meters

No commercial meter in the past has, to the writer's knowledge, attained exactly an indication given by equation 2. Curves *e* and *f* in Figures 2A and 2B represent typical time-deflection curves of actual meters which have been converted to equivalent demand intervals in *g* and *h* and are plotted decreasing from an initial value on semilog co-ordinates in order to easily compare them with the straight line *p* of $W_0\epsilon^{-kt}$.

An investigation of time-indication curves on any particular type of thermal meter indicates that there are small variations from meter to meter in the demand interval due to limitations in manufacturing control. We find also that in the same meter there are differences depending on the conditions of load and ambient temperature. We can reason from this that for a "15-minute demand interval" meter the actual demand interval should not be less than 15 minutes under any normal conditions of use in order not to read high on certain conditions of load, and we find practically all meters on the market which are considered satisfactory today for use as 15-minute demand interval meters fall within limits from 15 to 21 minutes interval.

When we consider differences in the curves in Figures 2A and 2B, we find another fundamental characteristic which although small might appreciably affect the meter readings in certain isolated conditions. This effect is easily demonstrated by applying a load which would give about full-scale deflection in 40 minutes and cut the load off at the end of five minutes. If we consider the "exponential" characteristic as shown in *p* as a standard of comparison, we find that a meter with a characteristic similar to *e* may read high by eight per cent of full scale, and a meter similar to *f* may read low by eight per cent at the instant the power is cut off. These should not be considered as errors as the definition of the time-deflection characteristic determines these differences. The meter following the *d* curve will continue to rise for a

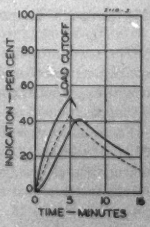


Figure 3. Time-indication curves for typical thermal watt-demand meters

Uniform load cut to zero before thermal equilibrium has been attained

little time after the power is cut off but will not quite reach the maximum value reached by the "exponential" characteristic. Figure 3 shows this characteristic graphically. It will be noted that meters with the f characteristic lag behind changes in load, while meters with the simple "exponential" or the e type of characteristic will change direction immediately in the direction of the new load value.

Simple Exponential Curve Desirable

From this brief discussion we can reason that as far as thermal meters are concerned, subject, of course, to any considerations which rate engineers may find of importance, the simple "exponential" time-indication curve published as characteristic of thermal meters is desirable. It is desirable if an acceptable time-indication curve is to be defined, for it allows a relatively simple mathematical definition of the shape of the curve. And more important is the fact that it is the only characteristic which will indicate "logarithmic" average for all types of loads.

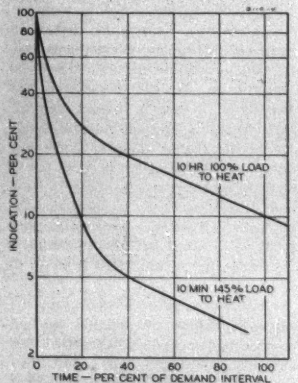


Figure 4. Time-indication curves of special thermal watt-demand meter

Cooling curves after loads as shown

Multibranch Thermal Circuits

The reason for the divergence of commercial-meter characteristics from the simple exponential has been attributed to diffusion.

Figure 4 shows performance curves of a 60-minute-interval thermal wattmeter illustrating an exaggerated condition of this diffusion which appeared in a paper presented by P. M. Lincoln before the Institute. The design constant, k was treated as a variable to account for the results. A slightly different treatment of the curves may be of interest and offers some advantages from a mathematical point of view in determining their shape.

The analogy shown in Figure 5 illustrates that multiple-branch thermal circuits may be expected to cool in a constant ambient according to the exponential:

$$W = W_0(A_1\epsilon^{-k_1t} + A_2\epsilon^{-k_2t} + A_3\epsilon^{-k_3t} \ldots + A_n\epsilon^{-k_nt}) \quad (3)$$

We can use the following expression to predict changes in indication when any constant load is applied:

$$W = W_0(A_1\epsilon^{-k_1t} + A_2\epsilon^{-k_2t} \ldots + A_n\epsilon^{-k_nt}) + W_1(1 - A_1\epsilon^{-k_1t} - A_2\epsilon^{-k_2t} \ldots - A_n\epsilon^{-k_nt}) \quad (3a)$$

In these equations A_1, A_2, k_1, k_2, and so forth are complicated functions of the storages and heat-transfer coefficients of the various branches. The form $W_0\epsilon^{-kt}$ referred to in various literature on thermal demand meters has been referred to above as a special case of equation 2, and equation 2 can be seen to be a special case of this more general equation 3a.

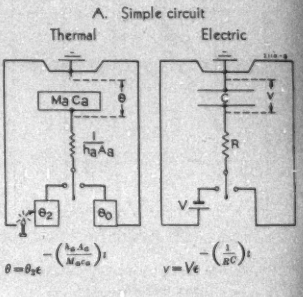
P. M. Lincoln has shown that the simplified expression is inadequate to explain the results of his tests unless we treat k as a variable. However, the results shown in Figure 4 can be predicted approximately from an equation such as 3, carried out to three terms as below:

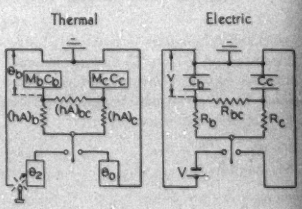
$$\text{Indication} = W_0(0.19\epsilon^{-0.921t} + 0.51\epsilon^{-0.2302t} + 0.3\epsilon^{-0.018t}) \quad (4)$$

This curve is plotted in Figure 6 where the first term is given as a dotted line, the second term as a dash line, and the third term as a dot and dash line, and the total as a full line. This curve checks reasonably with the per cent indication versus time curves (after ten-hour heating). Another group of curves (Figure 7) shows the heating curve for ten minutes at 145 per cent load and the following cooling curve when the load is removed, as given by constants in equation 4. Crosses indicate points calculated by considering the multiple-branch circuit as used in equation 4, and the circles represent points taken from Doctor Lincoln's meter data. The correlation is considered reasonably good for a first approximation of coefficients and exponents in the above equation. This allows us to think of meters of this nature as if they were the equivalent of multiple-branch thermal circuits with more than one constant k. Thus although such a meter reaches about 90 per cent of its final indication in 60 minutes, its final indication within reading limits will depend on the coefficient and power terms of one or more of the terms in equation 3. This may result in an extremely long time when considered from a testing point of view. In the above equation 4 for the 60-minute characteristic shown in Figure 6, k_1 corresponds to a demand interval of about 2.5 minutes and k_2 to an interval of about ten minutes and k_3 to an interval of about two hours. Doctor Lincoln has shown that meters with performance closer to the simple expression $W = W_0\epsilon^{-kt}$ can be built.

Time-Indication Curves of "Square" Scale Meters

When we consider the time-indication curves of a demand meter with a "square"





B_1, B_2, b_1, b_2 are functions of M_bC_b, M_cC_c, $(hA)_b$, $(hA)_c$, $(hA)_{bc}$ or C_b, C_c, R_b, R_c, R_{bc}

Figure 5. Comparison of thermal and electric circuit

M = mass
c = specific heat
C = capacitance
h = heat transfer coefficient
A = area
R = resistance
θ = temperature difference
v = voltage
θ_2 = initial temperature difference
V = initial voltage
θ_0 = ambient temperature

scale such as those used for ampere demand, we encounter further characteristic differences. The time-deflection characteristic of the wattmeter (as a simple thermal circuit) in general form has been given in equation 2 for constant applied loads. The time-deflection characteristic of a "square" scale meter can be expressed similarly, but since the indication is not proportional to the deflection but is proportional to its square root, we find the expression for indication:

$$A = \sqrt{A_0^2 \epsilon^{-kt} + A_1^2(1-\epsilon^{-kt})} \qquad (5)$$

where

A = instantaneous indication on a "square" scale (constant load)
A_0 = initial indication on a "square" scale
A_1 = final indication (constant load)

This reduces $A_0\epsilon^{-k/2\,t}$ when load is cut off. This has the same form as $W_0\epsilon^{-kt}$, and the cooling curve of time-indication will have the same general shape as the wattmeter, but since the exponent is $k/2$, it will take twice as long to cool to any percentage indication.

If the load starts at zero indication equation 5 reduces to

$$A = A_1\sqrt{1-\epsilon^{-kt}}$$

It can be seen that this does not have the same form as $W = W_1(1-\epsilon^{-kt})$, which is the equivalent on a uniform scale. These curves are shown graphically in Figure 8.

It may seem desirable to keep the shape of the time-indication curves of "square" scale and uniform scale meters on increasing loads (starting at zero) as nearly alike as possible. It has been proposed to decrease k for the ammeter to half the value for a wattmeter. This gives curve n shown in Figure 8 (as compared to curve i). It also gives a cooling curve m which is indeed slower (compared to i). Such a meter not only will differ in basic construction but also will theoretically differ on varying loads when compared to the uniform scale meter.

Another alternative suggested is to utilize the design and construction of the wattmeter, which requires changing the definition of demand interval so that the fraction of final indication of a "square" scale meter is the square root of that of a uniform scale meter. Thus, if the wattmeter is kept at 90 per cent for the demand interval definition, the ammeter would then be $\sqrt{0.90} = 0.95$ or 95 per cent. Such a meter does not have the same characteristic as a uniform scale meter, and its reading will differ on varying loads when compared to the uniform scale meter. (See k and l of Figure 8.) However, if the basic characteristic of interest is the heating effect, then the characteristic of this meter favorably compares with that of a uniform scale wattmeter. Perhaps in such a case, the scale marking should be in terms of amperes squared.

It is interesting to note that differences of watt- and ampere-demand meter readings on normally encountered loads have been sufficiently small to allow the use of meters with many of the varying characteristics described above with satisfactory results.

Operating Characteristics

With a knowledge of the fundamental operation characteristic of thermal meters, let us consider how it is affected with time or with changing conditions of load power factor, ambient temperature, and so forth. One of the important considerations in reliability of a meter of this kind is mechanical stability in which sturdiness of construction and constant friction are important factors. These factors are especially significant in meters which are to be maintained with a minimum of skilled servicing and equipment. Most meters with maximum indicating pointers have friction clutches to hold one pointer in the position of its maximum indication. Experience over a long period of time has shown that there is a more or less definite range of optimum friction in such cases. This is due to the fact that over the range that is normally used, the friction becomes more constant, the greater the magnitude of the friction. However, at the higher values of friction, its magnitude is objectionable, and at the very low values its variation with time, temperature conditions, and so forth, is equally objectionable. A value from 30 gram-millimeters

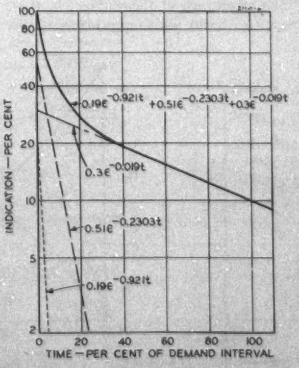


Figure 6. Time-indication curve including components

up, in a design which has been used for many years, has proved very satisfactory as far as consistency is concerned.

High Torque Desirable

To utilize frictions of this order of magnitude and still have them only approximately $1\frac{1}{2}$ or 2 per cent of the full-scale meter torque requires a meter torque of 1,500 to 2,500 gram-millimeters or a torque gradient of about 20 to 35 gram-millimeters per degree. Most thermal meters on the market today of the bimetal type do not utilize such high torques and rely on the lower friction torque remaining as constant as is required. The limiting features in obtaining higher torques are:

1. The amount of bimetal that is used, which is limited by other considerations such as space requirements, and so forth, and which has a definite influence on the demand interval of the meter.

2. The temperature at which the radiation or convection becomes an appreciable factor and the maximum temperature that the structure can stand.

To increase the operating temperature of the temperature-sensitive element without raising the temperature of the insulating parts of the heater requires better efficiency of heat transmission from the heater to the heated element. In recent years progress has been made toward greater efficiency and at the same time toward limiting convection and radiation by resorting to a bourdon tube actuating element with its bulb covered by a thermos bottle. This has gone a long way toward the achievement of high torque with low watts input. Inherent in a bourdon-tube design, however, is the hazard of leakage, one that must be eliminated by proper design, taking into consideration the long ranges of loads, power factors, and ambient temperatures over which modern meters are expected to function, and realizing the pressures that are set up in the tubes to meet these conditions. Added to this problem is one of choosing the best liquid for the bourdon tube. The problem is to obtain one which will not cause difficulty at lower temperatures and, at the same time, will have satisfactory temperature-expansion characteristics over the range required. With the use of demand meters in outdoor installations, this limiting feature assumes importance for temperatures below 32 degrees Fahrenheit and more especially, for temperatures as low as −40 degrees Fahrenheit, which although perhaps not common, might certainly be encountered in some installations. Many liquids are available and much experimental work has been done in this direction.[3]

Internally Heated Bimetal System

But when we consider difficulties of this nature together with others such as the hysteresis effects in bourdon-tube springs, and so forth, we realize the desirability of finding another method of attaining better heat-transmission efficiency which can be used with the time-tested bimetal spiral construction. Such a method is available if we heat the element by current through the bimetal itself. Here no loss is encountered, because the heat is generated where it is wanted. We thus get the highest possible efficiency of transmission and can limit radiation by means of controlled surfaces and convection by means of limited air spaces which, because of research work done in recent years, offers a practical solution.

If this arrangement is utilized to obtain the maximum efficiency of heat transmission possible, full-scale torques of the order of 2,000 grams-millimeters are readily obtained, and we can continue to use the time-tested bimetals as the activating element, where past experience and the vast amount of work that has been done by bimetal companies and meter manufacturers on heat treatment and the aging process insures stability of the bimetal characteristics. Moreover, uniformity of bimetal characteristics has recently been the subject of intensive investigation and has resulted in closer perfection of bimetal spirals with far more consistent characteristics than have been obtainable in the past.

Effect of Temperature Coefficient of Bimetals

One of the interesting phases encountered in taking advantage of the internally heated principle is occasioned by the fact that all suitable bimetals have a positive temperature-resistance coefficient. This has led to the following equations from a simple mathematical solution of Figure 10 giving the indication of such a meter:

$$W = 4I_R I \cos\theta\left[\frac{R_1R_2}{R_1+R_2}\right]+I_R^2[R_1-R_2]-I^2\left[\frac{R_1R_2(R_1-R_2)}{(R_1+R_2)^2}\right]$$

Since

$$I_R=\frac{E}{R_1+R_2}$$

Therefore:

$$W=4EI\cos\theta\left[\frac{R_1R_2}{(R_1+R_2)^2}\right]+E^2\left[\frac{R_1-R_2}{(R_1+R_2)^2}\right]-I^2\left[\frac{R_1R_2(R_1-R_2)}{(R_1+R_2)^2}\right]$$

If:

$R_1 = aR_2$ where a may be a variable as load conditions vary

$$W=4EI\cos\theta\left[\frac{a}{a+1}\right]+\frac{E^2}{R_2}\left[\frac{a-1}{(a+1)^2}\right]-I^2R_2\left[\frac{a(a-1)}{(a+1)^2}\right] \quad (6)$$

This general equation enables us to make a selection of a value for a when the meter is not excited and a value for the ratio of I to I_R which will give satisfactory values for W when $EI\cos\theta$ is kept constant, and ambient temperature, voltage, power factor, or load is changed through limits ordinarily met in service. These are two design constants which the design engineer can vary to obtain the optimum condition for this sort of meter.

When a is equal to 1.0, the last two terms of this equation disappear. However, if a differs slightly from 1.0 we can take advantage of the changes in these last two terms with temperature, power factor, and so forth, to obtain some slight compensation for small inherent errors.

An important bimetal characteristic which enables a simple mechanical construction to meet these requirements is the fact that the torque per degree temperature rise is independent of the length of a bimetal coil. We can therefore buck two bimetal coils on a single shaft to obtain complete temperature compensation at no load, and at the same time get the required ratio in resistances by using coils of different lengths. Modern bimetal-coil manufacturing procedure has made possible the satisfactory matching of coils of this nature.

Data on Actual Meter

It is interesting to note how these observations are confirmed in a sample meter built to take advantage of this high efficiency heat generation thus giving a high torque bimetal meter. Figure 9 illustrates such a meter and Figure 10 gives its wiring diagram. The most important operation characteristics are tabulated in Table I and indicate the possibilities which may be utilized in development along these lines. Important is the fact that generation of heat in the bimetals allows such rapid diffusion of heat that there are possibilities that the necessary voltage heat-up before test can be shortened and that the time deflection curves actually will follow the desirable simple exponential curve.

Conclusions

A great deal must be discussed in elaborating on the various time-deflection characteristics obtainable in thermal watt-demand meters but experience has indicated that since demand is not an exact quantity, and since rate structures must vary for different classifications of load,

Figure 7. Time-indication curves

Constant load cut to zero before thermal equilibrium has been attained (showing components)

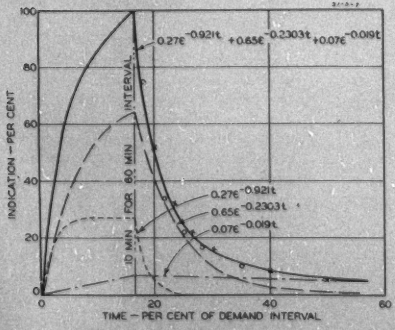
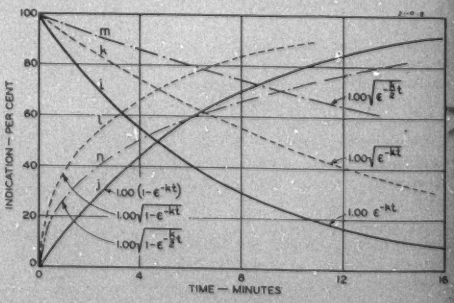


Figure 8. Time-indication curves

Two types of "square" scale meters compared to a uniform scale meter



the various kinds of characteristics discussed above all seem to be satisfactory for most demand measurements.

Accuracy of thermal meters today is considerably better than it was several years ago, and sturdiness, together with high torque, are desirable qualities to sustain this greater accuracy.

This high torque is obtainable with the time-tested bimetal type of thermal watt-meter by taking advantage of the "internally heated" principle which gives maximum heat transfer efficiency and gives a time of response characteristic much closer to the ideal simple exponential than has been attained in commercial meters in the past.

The preceding data of a typical meter developed to give high torque by means of internally heated bimetal construction indicates that a superior all-around meter has been designed, and that this principle of operation is worthy of consideration as the basic design of thermal watt-demand meters.

Appendix A[6]

The general time-deflection response equation is developed here for a device indicating the difference in temperature of two similar bodies connected by a thermal shunt when constant heat inputs (or zero input) is applied to each body, the bodies starting at any initial temperature or temperature difference.

Let

H_1 = rate of heat applied to A (gram calories per second)

H_2 = rate of heat applied to B (gram calories per second)

h = thermal conductivity from A or B to ambient (gram calories per second per degree centigrade)

Q = thermal conductivity of shunt (gram calories per second per degree centigrade)

θ_{a1} = initial temperature of A (degrees centigrade)

θ_{a2} = initial temperature of B (degrees centigrade)

θ_1 = instantaneous temperature of A above θ_{a1} (degrees centigrade)

θ_2 = instantaneous temperature of B above θ_{a2} (degrees centigrade)

M = heat stored in A or B per degree centigrade (gram calories)

The conservation of energy equations become

$$H_1 dt - Q(\theta_1 - \theta_2 + \theta_{a1} - \theta_{a2})dt = h(\theta_{a1} + \theta_1)dt + M d\theta_1$$

$$H_2 dt + Q(\theta_1 - \theta_2 + \theta_{a1} - \theta_{a2})dt = h(\theta_{a2} + \theta_2)dt + M d\theta_2$$

Let

$$\theta_{a1} - \theta_{a2} = W_0 \text{ and } (\theta_{a1} + \theta_1) - (\theta_{a2} + \theta_2) = W \text{ and } \theta_1 - \theta_2 = W_2$$

$$d\theta_1 + d\theta_2 = d(\theta_1 + \theta_2) = dW_2$$

The time-deflection response of thermal meters is proportional to the temperature difference W.

Then by subtraction and substitution

$$(H_1 - H_2)dt - 2Q(W_2 + W_0)dt = h(W_2 + W_0)dt + M dW_2$$

$$\frac{dW_2}{dt} + \frac{h+2Q}{M} W_2 = \frac{H_1 - H_2}{M} - \frac{h-2Q}{M} W_0$$

Let

$p = d/dt$, and $\mathbf{1}$ = Heaviside's unit operator (see reference 4)

$$\left[p + \frac{h+2Q}{M}\right] W_2 = \left[\frac{H_1 - H_2}{M} - \frac{h+2Q}{M} W_0\right] \mathbf{1}$$

$$W_2(t) = \left[\frac{H_1 - H_2}{M} - \frac{h+2Q}{M} W_0\right] \times \left[\frac{1}{p + \frac{h+2Q}{M}}\right] \mathbf{1} \quad (1)$$

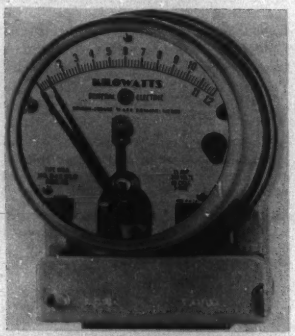


Figure 9. Single-phase watt-demand meter
15 amperes, 240 volts, 60-cycle, three-wire

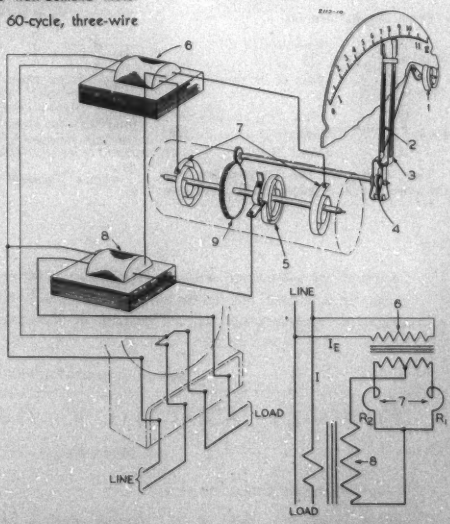


Figure 10. Wiring diagram for single-phase watt-demand meter

1. Calibration adjustment
2. Kilowatt indicator
3. Maximum - demand indicator
4. Friction clutch
5. Zero adjustment spring
6. Potential transformer
7. Thermostat metal
8. Current transformer
9. Drive gear

From simple operational calculus

$$W_2 = \left[\frac{H_1 - H_2}{M}\right]\left[\frac{M}{h+2Q}\right] \times \left[1 - \epsilon^{-\frac{h+2Q}{M}t}\right] - \left[1 - \epsilon^{-\frac{h+2Q}{M}t}\right] W_0$$

By definition above

$$W = W_2 + W_0$$

$$W = \left[\frac{H_1 - H_2}{h+2Q}\right]\left[1 - \epsilon^{-\frac{h+2Q}{M}t}\right] + W_0 \epsilon^{-\frac{h+2Q}{M}t}$$

Let

$$\frac{H_1 - H_2}{h+2Q} = W_1 \text{ and } \frac{h+2Q}{M} = k$$

Then

$$W = W_1(1 - \epsilon^{-kt}) + W_0 \epsilon^{-kt} \quad (2)$$

Appendix B

The response of an object such as a theoretical thermal watt-meter is developed here for three conditions of loading:

(a). Where the load is any function of time.

(b). Where the load is constant.

(c). Where the load increases at a constant rate.

The response is of such a nature that it is directly proportional to the temperature of a mass where the mass is supplied with a heat input proportional to the load; and this input is utilized both in raising the temperature of the mass and in supplying the heat escape which is proportional to the temperature of the mass.

Let

h = thermal conductivity from mass to ambient (gram calories per second per degree centigrade)

Table I. Characteristics of a 15-Ampere 240-Volt Three-Wire Single-Phase Thermal Watt-Demand Meter

(Typical Average Values for an Experimental Internally Heated Design)

Torque (full-scale)		2,200 g-mm
Scale length		Approximately 4 inches
Power factor influence (7.2 kw) referred to pf 1.00	0.5 pf lag	Less than 2%
	0.5 pf lead	Less than 2%
Frequency influence referred to 60 cycles		Negligible
Temperature influence (12.0 kw, 1.0 pf) referred to 25 C	+50 C	Less than 2%
	−20 C	Less than 2%
Voltage influence (10% change in voltage) referred to rated voltage		Less than 2%
Rising time-deflection curve shape		"Simple exponential" (Figure 2B, curve p)
Demand interval		Approximately 17 minutes
Watts loss	Potential (240 volts)	2.5
	Current (12 kw, pf 1.0)	9.0
Size		Standard single-phase watt-hour meter size

$kf(t_1)$ = rate of heat applied (gram calories per second)

θ = temperature (instantaneous) of mass which is proportional to meter deflection (degrees centigrade)

t = time (minutes)

W = angular deflection

The conservation of energy equation becomes

$$kf(t_1)dt = h\theta dt + Md\theta$$

Then

$$\frac{d\theta}{dt} + \frac{h}{M}[f(t_1) - \theta] = k[f(t_1) - \theta] \text{ where } k = \frac{h}{M}$$

Let

$\frac{d}{dt} = p$, and $\mathbf{1}$ = Heaviside's unit operator (see reference 4)

$$(p+k)\theta = kf(t_1)\ \mathbf{1}$$

$$\theta = \frac{k}{p+k}[f(t_1)]\mathbf{1} = k\left[\frac{1}{p}\right]\left[\frac{p}{p+k}\right][f(t_1)]\ \mathbf{1}$$

From Borel's theorem:

$$Y_1(p) = \frac{p}{p+k}\,\mathbf{1} = \epsilon^{-kt_1}$$

$$Y_2(p) = f(t_1)\ \mathbf{1}$$

$$\theta = k\int_0^t \epsilon^{-k(t-t_1)} f(t_1)\,dt_1 \qquad (1a)$$

This shows that the temperature θ of the indication W is proportional to the sum of all the instantaneous values of $f(t_1)$ each multiplied by a factor, $\epsilon^{-k(t-t_1)}$, which decreases exponentially as the time, t_1, of the instantaneous value of $f(t_1)$ is taken backwards from the time, t. The value t is the time of the instantaneous value of the indication W or temperature θ being considered.

(a). This function,

$$\kappa\int_0^t [f(t_1)][\epsilon^{-k(t-t_1)}]dt_1$$

can be designated by definition as the logarithmic average of $f(t_1)$ at any time, t, and is the value a simple theoretical thermal watt-demand meter indicates.

(b). If $f(t_1)$ is a constant such as W_1 after starting from zero indication, the expression becomes

$$W_1(1-\epsilon^{-kt})$$

When the transient ϵ^{-kt} becomes small, the meter will read W_1 or the equivalent of a block interval type of meter.

(c). But if $f(t_1)$ is directly proportional to time such as At the expression reduces to

$$At - \frac{A}{k} + \frac{A}{k}\epsilon^{-kt}$$

This indicates that after the transient $A/k(\epsilon^{-kt})$ becomes small (about three demand intervals), the meter will have approached a constant increase in deflection:

$$\frac{d\theta}{dt} \text{ when } \epsilon^{-kt} \text{ is small} = \frac{d}{dt}\left(At - \frac{A}{k}\right) = A$$

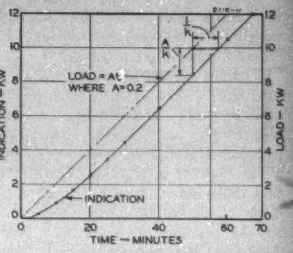


Figure 11. Indication lag of a thermal watt-demand meter on a constantly increasing load

x—points for curve

$$At - \frac{A}{k} + \frac{A}{k}\epsilon^{-kt}$$

where $A = 0.2$

$k = 0.135$

(demand interval = 17 minutes

Also since the deflection, if it followed watts input, instantaneously would be proportional to At.

And since the deflection, after the transient term becomes small, is $At - A/k$; therefore the reading will lag in deflection by A/k, and since the rate of change of deflection is A, the reading will lag in time by $1/k$.

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